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ALPINE SPORTS INJURIES IN FINLAND:

A RETROSPECTIVE ANALYSIS OF SKIING AND SNOWBOARDING INJURIES

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ACADEMIC DISSERTATION

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ABSTRACT

The equipment and body mechanics in skiing and snowboarding are different, exposing participants to a distinctive array of risks and injuries. Recreational skiing and snowboarding have gone through major changes during the last decade due to rising popularity of terrain parks and evolution of equipment. The modern skis provide the opportunity to ski faster with less skill than with traditional skis.

The aim of this thesis was to provide information on the incidences and the nature and mechanisms of injury, in both recreational and competitive alpine skiing and snowboarding in Finland.

Study I covered six seasons (2006–2012), assessing injured recreational alpine skiers and snowboarders at the Levi Ski Resort Ltd., Finland. The data was collected from the ski resort's files which registers ski lift rides, injuries and conditions leading to injury on a standardized form of all injured persons. In study II, data of injuries in Finnish ski racers during the seasons of 2009 and 2010 were retrospectively studied. The data collection (patient characteristics, mechanism and type of injury, the length of recovery and a subjective outcome at six months post injury) was conducted with a standardized written questionnaire. For study III, all patients with tibial fracture in recreational skiing or snowboarding were reviewed in four hospitals between years 2006–2012. The fracture morphology and injury mechanism were analysed to compare fracture patterns between these two sports. Study IV focused on traumatic brain injuries. All patients referred to the Trauma Unit of Helsinki University Hospital with acute head injury due to skiing or snowboarding between years 2006 and 2015 were reviewed.

The overall injury incidence in recreational skiing and snowboarding in study I was 0.98 injuries per 10 000 lift runs. Snowboarders were more likely to sustain upper extremity injuries when compared to skiers (59% vs. 34% $p<0.05$) whereas skiers were more likely to injure lower extremity (43% vs. 17%, $p<0.05$). Most of the accidents (n=2062, 72%) took place on slopes, but injuries in terrain parks were more likely to be more serious injuries (22%, vs. 9%, $p< 0.05$).

In study II, the lower extremity was the most commonly injured body area (n=39, 64%) in ski racing. Knee injury was the most common injury (n=21, 34%), followed by tibial fracture (n=16, 26%). The most common tibia fracture type in recreational skiers (study III) was spiral shaft fracture (n=180, 53%), followed by tibial plateau fractures (n=62, 18%). Whereas among snowboarders tibial plateau fractures were most common (n=7, 23%). In study IV, the majority (n=51, 70%) of head injuries were concussions without injury findings in computed tomography. Seventeen patients (24%) had serious to critical injuries graded by Abbreviated Injury Scale. Patients who fell while jumping or trying to balance on handrails in urban environment were more likely to be admitted to ICU than patients injured on skiing slopes (32% vs. 10%, $p<0.05$).

In conclusion, the injury incidence in recreational skiing and snowboarding was lower than in previous studies conducted in the United States and continental Europe, but similar to studies from other Nordic countries. Among ski racers the high number of lower leg fractures is alarming when comparing to previous studies. Additionally, the number of recreational skiers’ tibia plateau fractures was higher than in earlier studies conducted before the era of modern skies. Head injuries occurring in small hills and in urban environments can be serious and potentially fatal, and the profile and severity of these is comparable to those on alpine terrain.

TIIVISTELMÄ

Antti Stenroos. Alppilajien vammat Suomessa. Ortopedian ja traumatologian klinikka, Lääketieteellinen tiedekunta, Helsingin yliopisto. Helsinki 2018.
Alppihiihto ja lumilautailu ovat yksiä suosituimmista talviurheilulajeista Suomessa. Vuosikymmenten aikana molemmissa lajeissa välineet ja tyyli ovat muuttuneet merkittävästi. Lajien mekaniikka on erilainen, lumilautailijat laskevat sivuttain molemmat jalat kiinnitettyinä lautaan, kun taas laskettelijat laskevat kasvot menosuuntaan päin jalassaan jäykät monot jotka kiinnittyvät suksiin siteillä, jotka aukeavat tarvittaessa. Nämä erot johtavat merkittäviin eroihin molempien lajien vamma mekanismeissa ja vammojen tyypeissä.
Tässä väitöskirjatutkimuksessa kartoitettiin lumilautailuun ja alppihiihtoon liittyvien vammojen määriä ja tyyppejä, sekä harrastajien että kilpailijoiden keskuudessa. Ensimmäisen osatyön aineisto koostui Levin hiihtokeskuksessa vammautuneista potilaista. Aineisto kerättiin Levin ensiavun aineistoista sekä hissiyhtiön lipunmyynti sekä hissien käyttömäärä aineistoista. Toisessa osatyössä aineisto kerättiin retrospektiivisesti kyselytutkimuksella kilpa-alppihiihtäjiltä, koskien vamman tyyppiä, vammamekanismia sekä poissaoloaikaa lajiharjoittelusta. Kolmannessa osatyössä arvioitiin rinteessä syntyneiden säärimurtumien määrää ja tyyppiä neljässä sairaalassa. Murtumien vammamekanismia ja morfologiaa arvioitiin ja verrattiin lumilautailijoiden ja alppihiihtäjien välillä. Neljännessä osatyössä keskityttiin vain traumaattisiin aivovammoihin Helsingin alueella. Analysoimme kaikki potilaat, jotka olivat lumilautaillessa tai alppihiihtäessä kaatunut johtaen aivovammaan.

Yläraajavammat olivat yleisimpiä lumilautailijoilla, kun taas alppihiihtäjillä alaraajavammat olivat yleisimpiä. Suurin osa vammoista johtui kaatumisesta samalla tasolla, mutta hyppyreissä tapahtuvat vammat olivat vakavampia. Loukkaantumisten määrä Levillä oli 0.98 vammaa 10 000 hissinousua kohden Polvivammat olivat yleisimpiä vammoja kilpa-alppihiihtäjillä, mutta huomionarvoista oli myös säärimurtumien yleisyys. Harrastelijoiden keskuudessa tyypillisin säärimurtuma oli diafyysin kierteinen murtuma ja seuraavaksi yleisin oli polviniveleen ulottuva säärimurtuma. Lumilautailijoiden yleisin murtumatyyppi oli polviniveleen ulottuva säärimurtuma. Suurin osa päävammoista oli aivotärähdyksiä, mutta neljänneksellä potilaista oli vakava tai kriittinen päävamma.

Voimme todeta, että vammojen määrä levillä oli alhaisempi kuin aikaisemmissa keskieurooppalaisissa ja amerikkalaisissa tutkimuksissa. Kilpa-alppihiihtäjien säärimurtumien määrä oli huolestuttavan korkea verrattuna aikaisempiin tutkimuksiin. Lisäksi suurimäärä polviniveleen ulottuvia säärimurtumia harrastelijoiden keskuudessa on korkeampi kuin aikaisemmissa tutkimuksissa, jotka on tehty ennen nykyaikaisia välineitä. Päävammat, jotka syntyvät kaatuessa pienissä rinteissä ja hiihtäessä ja lumilautaillessa kaduilla on vakavia ja verrattavissa vuoristoissa tapahtuviin vammoihin.

LIST OF ORIGINAL PUBLICATIONS

This thesis is based on the following publications:

I. Stenroos A, Handolin L: Incidence of recreational alpine skiing and snowboarding injuries: six years' experience in the largest ski resort in Finland Scandinavian Journal of Surgery 2015 Jun;104(2):127-31

II. Stenroos A, Handolin L: Alpine skiing injuries in Finland – a two-year retrospective study based on a questionnaire among ski racers. BMC Sports Sci Med Rehabil. 2014 Feb 24;6(1):9

III. Stenroos A, Pakarinen H, Jalkanen J, Mälkiä T, Handolin L: Tibial fractures in alpine skiing and snowboarding in Finland: A retrospective study on fracture types and injury mechanisms in 363 patients. Scandinavian Journal of Surgery 2016 Sep; 105(3): 191–196.

IV. Stenroos A, Handolin L: Head injuries in urban environment skiing and snowboarding; a retrospective study on injury severity and injury mechanisms. Scandinavian Journal of Surgery 2017 Nov 1 (Epub ahead of print)

ABBREVIATIONS

ACL	Anterior Cruciate Ligament
AIS	Abbreviated Injury Score
AO	Arbeitsgemeinschaft für Osteosynthesefragen
BIAD	Boot-Induced Anterior Drawer
CT	Computer Tomography
DH	Downhill
FIS	Fédération Internationale de Ski
GCS	Glasgow Coma Scale
GOS	Glasgow Outcome Scale
GS	Giant Slalom SL Slalom
ICD-10	International Statistical Classification of Diseases and Related Health Problems, 10th volume
ICU	Intensive Care Unit
LEER	Lower Extremity Equipment Related Injuries
MDBI	Mean Days Between Injuries
SBB	Ski-Plate-Binding-Boot
SG	Super G
TBI	Traumatic brain injury
UCL	Ulnar Collateral Ligament
TP	Terrain Park
WC	World Cup

1. INTRODUCTION

The downhill skiing sport has for years had a reputation for skiers being afflicted by frequent knee and lower leg injuries. There are a variety of epidemiological studies into skiing and snowboarding injuries from all over the world [1-16] but there is a need for local studies if one wishes to devise useful preventive measures which would reduce the number and severity of injuries. Ski resorts in Finland are smaller with fewer steep slopes compared to North American and European resorts. In addition, most of the Finnish ski resorts are well groomed and use artificial snow makers to make the slopes safer for the skiers.[7] Earlier studies[1-6] have noted that injury rates are lower in Nordic countries than in continental Europe or North America. [9,10,17,18] It has been speculated that besides easier slopes the Nordic people are more experienced skiers than American and European skiers, which could be one of the reasons for lower injury rates in the Nordic countries compared to other countries around the world. In snowy Nordic countries people often start skiing as children and possibly acquire more experience and a higher level of skill than the average once-a-year skier from the snow-free parts of the American and European continents.

Only two studies reporting epidemiology of skiing injuries have been published in Finland [2,19] and only one in Sweden.[20] Two of these studies are published before the skiing equipment underwent through major changes and terrain parks (TP) become popular. [21] One is a case control [5] study that took place from 1998 to 2006 at a Swedish ski resort and demonstrated that injury incidence has been decreasing during the study period. No studies concerning injury rate in street/urban skiing or snowboarding exists. Only one study [22] conducted on indoor skiing in Netherlands with similar vertical heights as the small skiing hills in Helsinki area has been published.

The aim of this thesis was to provide information on the incidences, mechanisms of injury and nature of both recreational and competitive alpine skiing and snowboarding injuries in Finland.

2. REVIEW OF THE LITERATURE

2.1 Skiing in Finland

2.1.1 History

Skiing has a history of almost five millennia in the Nordic countries; the oldest known ski is 5000 years old and was found in northern Sweden and ski fragments found in northern Russia have been carbon dated as even more ancient, 8000-7000 BC. [23] The word "ski" comes from the Old Norse word "skíð" which means "split piece of wood or firewood" and word slalom is also a Norwegian word for a sloping track (sla=slope, lom=track).[23] Until the mid-19th century, skiing was primarily used as a means of transport. It was characterized by fixed-heel bindings that were attached at both the toe and the heel of the skier's boot instead of a binding that was attached at the toes of the skier's boots as is the case in modern-day cross country-skiing.

The first skiing competitions are reported to have been held in the mid-19th century in Norway. A few decades later, the sport spread to continental Europe.[24] Alpine skiing debuted in the Olympic programme in 1936 in Garmisch-Partenkirchen. In the late 1920s, the Finnish Women's Physical Education Association (SNLL) developed unconventional forms of pedagogical skiing instruction. They abandoned traditional flat terrain skiing and sought innovative influences from abroad and downhill skiing was also introduced in Finland.[25]

The first official ski slope in Finland was opened in Bad Grankulla health spa in 1933 in the Greater Helsinki region. The first Finnish skiing resorts were built at sites of major cross-country skiing races and in the late 1930's new slopes were cleared for slalom races and recreational skiing. The first ski lift was built close to Helsinki in Kiianlinna 1949 by the Finnish skiing pioneer, Karl Ebb.[25] The slope is still in daily use. The building of slopes and ski lifts and the emergence of organized slalom racing competitions gradually separated alpine skiing from its cross-country counterpart. The first slalom competition was organized in Puijo in 18.3.1934 and the first national championships in Salla in 1937.[26]

2.1.2 Ski resorts in Finland

Today in Finland, on average every fifth member of the population takes part in downhill sports at least once each year and the Finnish Ski Resort Association estimates that 100,000-200,000 are snowboarders. Skiing has become one of the most popular global winter sports with an estimated 200 million participants worldwide. [27]

The 68 ski slopes in Finland are small, there is no skiing above 800 meters of sea level (range 30-720 meters) The highest resort (Ylläs ski resort) is 720 meters high above sea level; the smallest sites have only about 30 meters of vertical elevation. According to the annual number of visitors, the Levi Ski Resort is the busiest ski resort in Finland with over 4 million ski-lift runs in the season of 2011-2012.[27] Many of the smaller resorts are susceptible to variable snow and weather conditions especially in southern Finland. Conditions are more stable in northern Finland and the ski season is 130–140 days on average, starting normally in late October and lasting until May. All the ski resorts in Finland utilize artificial snowmaking machines to ensure adequate snow conditions. The season is usually longest in the Ruka resort in Kuusamo, starting usually on October 1st and lasting until the end of June.[27]

2.1.3 Alpine skiing races in Finland

Each year, Ski Sport Finland organizes approximately 25 national competitions for children (under ages of 14 and 16) and many local competitions for younger children. For adults (older than 16 years) approximately 50 Fédération Internationale de Ski (FIS) regulated competitions and 2 World Cup and 2 European Cup competitions are organized annually. Competing in alpine skiing starts from the under 8 years of age (U8) in Finland. The competition system is age related and divided into age ranges spanning two years. Younger children take part in local competitions and local cups and unofficial national championships. Adolescents (U14 and U16) have a national cup and unofficial national championships. From the age of 16, the Finnish Championships are organized for youth and adult athletes in all four disciplines. From 16 years of age, the skier requires a license from FIS to participate in national and international competitions and skiers are thereby ranked within the FIS international ranking system with FIS points. The FIS points are given in the different disciplines and are based on the skier´s race results. In Finland, each year about 700 skiers hold a Ski Sport Finland's competitors license although most of the active alpine ski competitors are children. Thus, the percentage of adults (over 16 years of age) is approximately 20% and that of Masters (over 35 years of age) 10% respectively. [28]

Since 2010, Ski Sport Finland has organized that physicians should be present at all ski races in Finland. The group of Alpine Race Doctors consists of 20 volunteer doctors who supervise competitions and cooperate with the local emergency service to help injured athletes. In Finland, it is also the race doctor's responsibility to record any injuries, which are logged into an up-to-date alpine ski injury survey.

2.1.4 Alpine skiing

Alpine skiing has later evolved into several different subgenres in addition to the distinction between recreational and ski racing. It can be roughly divided in the following categories: ski racing, freestyle skiing, off-piste skiing and recreational skiing. FIS organizes competitions in ski racing, freestyle skiing and snowboarding. The Freeskiing World Tour (FWT) is the biggest off-piste skiing competition organizer. Furthermore, there are several smaller organizations and federations that regulate smaller competitions and subgenres.

FIS has regulated the specific competition disciplines in ski racing defining the course length, vertical drop and course setting. The four disciplines are: Slalom (SL), which has the shortest course and quickest turns with the distance between gates being 7-12 meters. Giant slalom (GS) consists of medium and long turns with 20-30 meters distance between gates. Super giant slalom (SG) consists of long and medium turns with jumps; the minimum distance between the gates must be 25 meters. Downhill (DH) is the fastest event with speeds up to 150 km/h and usually large natural or man-made jumps. It has smallest number of turns and the longest running time.[29]

Fig. 1. The Four alpine skiing disciplines presented in clockwise direction. Slalom, Giant Slalom, Super G and Downhill

In FIS regulated competitions, freestyle skiing is divided into five disciplines: aerials, moguls, ski cross, half-pipe and slopestyle.

Fig 2. Skier performing a spin on a terrain park.

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In Aerials, the skier launches him/herself off 2-4 meter jumps rising several meters in the air in order to perform multiple flips and twists before landing on an inclined landing hill.

Mogul skiing consists of one timed run of free skiing on a steep, heavily moguled course with two jumps. Ski cross is a ski racing discipline where 4 skiers race down a course that includes gates big-air jumps and high-banked turns.

In an attempt to address safety issues by reducing collisions between regular slopes users and freestylers/snowboarders, resorts began to provide specific areas for the latter group called terrain or snow parks (Figure 2).[30] These terrain parks(TP) have become more popular and the vast majority of resorts now have one. In Slopestyle athletes ski or snowboard a down a slope that includes a variety of obstacles including rails, jumps and other TP features.

TPs contain several forms of jumps of varying sizes usually between 2-20 meters to allow skiers and snowboarder to perform various tricks such as spins and somersaults while airborne. It seems that the required run speeds vary also between 15 km/h and 80 km/h. TPs attract a unique demographic of ski resort users since their users are predominately younger males who consider themselves as experts.[31]

Freestyle skiing and snowboarding have further evolved into urban skiing and snowboarding (Figure 3). In urban skiing/snowboarding, the performers try to balance on handrails and jump off and on buildings and other features. Urban riding tricks are similar to those done in terrain parks with jumps and man-made obstacles, but take place in residential and industrial urban areas that are not designed for skiing or snowboarding. The major difference to TPs is often that tricks are performed on stairs and nearby standing stationary objects. Urban skiing and snowboarding combine high speed with the potential for collision with stationary objects, as well as a risk of falling from heights. Helsinki has a reputation as the ‘mecca’ of urban rails because of the good snow conditions and officials in the Finland are not seen as being strict about urban skiing like their counterparts in USA. The lack of steep mountains in Finland may be one reason for growing popularity of urban skiing and snowboarding in the Greater Helsinki during the last decade. There are only estimates of the numbers of urban skiers and snowboarders; these vary between 200 and 1000 regular skiers and snowboarders in Helsinki. Helsinki is one of the most popular filming locations in urban skiing and snowboarding movies. Film crews from around the world are a common sight in Helsinki’s numerous skiing/snowboarding spots. [32]

Fig. 3. Snowboarder jumping of a handrail in an urban environment.

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Freeriding is a sport that has experienced tremendous growth during the last few years. There is also an increasing trend for recreational riding in unmarked and unpatrolled areas (e.g., backcountry/off-piste snowboarding, ski touring, extreme skiing). Freeriding takes place on un-groomed snow on extremely steep, mountainous slopes. As the name extreme skiing implies, the sport is very dangerous with a constant risk of serious falls and the risk of being buried under an avalanche.

Fig. 4. Freeskier jumping off a small boulder

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2.1.5 Snowboarding

Snowboarding evolved from surfing and from a winter toy called "Snurfer" during the late 1970's. The first official snowboard competition was held in 1982 in Vermont USA. Snowboarding remained a relatively small-scale sport during the 80's. Most of the ski resorts did not allow snowboarding on their official slopes. As years went by, gradually snowboarding became more widely accepted. By 1990, most major ski areas had separate slopes for snowboarders. Today, almost all ski areas in North America and Europe allow snowboarding. During the 1990s, the popularity of snowboarding increased rapidly and this was paralleled by the number of injuries on the slopes.[17,18,33,34] It has been estimated that snowboarders are three times more likely to be injured than skiers and furthermore the injury rate appears to be increasing.[35,10,15,33,36,37]

2.2 Skiing and snowboarding equipment

The equipment and body mechanics of skiing and snowboarding are different, exposing participants to a distinct assortment of risks and different types of injuries. The greatest difference is the plane of stance with respect to the direction of travel; snowboarders travel sideways and have both feet fixed to one board with soft boots and non-releasing bindings. Today snowboard boots are mostly considered soft boots, though alpine snowboarding uses a harder boot similar to a ski boot. Size and shape variances in the boards accommodate for different snow conditions and riding styles. Both skies and snowboards are generally constructed of a hardwood core, which is sandwiched between multiple layers of fiberglass.

Both sports (skiing and snowboarding) have undergone continued growth over the past three decades as a result of both new technologies and increased terrain development. Improved equipment has increased performance and enabled skiers to gain more speed on even more complex terrain. Snowboards have gone from handmade wooden boards without steel edges for use in deep snow to hardwood core boards with steel edges. There have not been major changes in the snowboarding equipment since introduction of the soft boot.

Ski-binding-boot-systems (SBB) have evolved and skis have been shaped like an hourglass since the early 2000s. Critical improvements in bindings began in the early 1970s with no appreciable changes after 1980s. One of the primary design criterions of ski boots and bindings was to protect the skier from tibia and ankle fractures. SBB-systems have two functions: retention and release. The binding should release the leg and ski boot from the ski when loads approach the threshold of injury to the lower extremity. Similarly, the binding should hold the boot in the ski when loads necessary to maneuver through all types of terrain and snow conditions are encountered, as long as there is no danger of injury. [38-40]

The important effect of the hourglass side cut is that when the ski is tilted on edge on the snow, the curve will try to lead the ski around a circular path. The modern side cut will make the ski turn itself [41] providing the opportunity to ski faster with less skill than with traditional skis.[42] With improvements in ski equipment and higher participation rates as well as increased accessibility for the general public, it is not surprising that a greater number of more traumatic injuries have occurred even though injury rates are lower than in the 1970's. [6,9,37,43] Twin-tip skis were introduced in the beginning of the 21st. century and became very popular during following years. Twin-tip skis are designed to enable a skier to take off and land backwards while jumping as well as allowing skier to ski backwards down a slope.

The ski racing equipment varies between disciplines and gender. In contrast to recreational skiing, specific rules for equipment are determined by FIS. In the speed disciplines, i.e. DG and SG, long and straight skis are favoured, since they provide greater stability at high speed. In the GS and SL, skiers have to carve tighter turns; thus the ski waist width, on-edge angle and ski flexion/stiffness are critical factors.[44]

2.3 Injury mechanisms in skiing and snowboarding

Fig 5. Traditional ski and modern carving ski

The majority of the skiing injuries are related to falls on the same level and collisions with natural and man-made objects.[5,9,43,45] In snowboarders, while falls on the same level also seem to be the commonest cause of injury, the next most ubiquitous is attributable to jumps.[5,13] It has been reported that head injuries mainly occur as a result of collisions with different objects: the snow surface, other skiers, immovable objects in the natural and man-made environments.[45,46] In a video analysis of World Cup skiers conducted by Bere et al.[47] the main finding was that most of the injuries to the head and upper body resulted from crashes (96%), while the majority of knee injuries occurred while turning (83%). Gate contact contributed directly or indirectly to 30% of all injuries, while only 9% occurred due to contact with safety nets/material.

2.3.1 ACL injury mechanisms in skiing

The ACL resists anteriorly directed force and internal rotation forces applied on the tibia relative to the femur. [48-50] Tibial internal rotation forces are implicated in most ski-specific ACL injury mechanisms. [51] Hame et al.[48] found in their cadaveric study that ACL strain was greatest at 0° of knee flexion and in forced hyperflexion in combination with tibial internal rotation torque. The knee flexion angle appears to be of particular importance in skiing regard to the amount of ACL strain. [52,53]

At deeper angles of knee flexion, joint geometry and lines of action for the quadriceps and hamstring muscles lend toward decreased anterior shear forces and less ACL strain. [52-54] Landing back weighted may not be sufficient to load the ACL. [52-54] However, landing back weighted with simultaneous strong eccentric quadriceps contraction may generate a sufficiently large shear forces to cause ACL injury. [48-50,52-54] Additionally, equipment factors including SBB-systems and shape of the ski [38,47,55-57] and use of a stiffer ski boot are thought to increase anterior shear forces on the tibia during jump landings.[58]

With the new modern hourglass shaped skis, the "slip and catch" mechanism of the ACL injury has become the most common injury mechanism among ski racers and recreational skiers.[57,59] In slip and catch, the skier loses balance in the backward and inward direction, and loses snow contact and pressure on the outer ski.[57] Subsequently, the inside edge of the outer ski abruptly catches the snow surface, leading to excessive knee joint compression, knee valgus, and internal rotation.[60] The general consensus is that the flexion-internal rotation injury mechanism is especially attributable to this kind of skiing equipment.[61] Bere et al.[60] analyzed video recordings from 20 elite alpine ski racers who sustained ACL injuries during competition. The slip-catch mechanism occurred most frequently (50% of cases) and happened while skiing (typically during a turn).

Other ACL injury mechanisms have been described in the literature among skiers. These are the Boot-Induced Anterior Drawer (BIAD),[60] the valgus external rotation mechanism, the dynamic snowplow and the Phantom Foot.[62] In BIAD, the ACL is damaged when the top of the boot drives the tibia forward while skier falls/loses balance backwards, resulting in the generation of a force that causes an isolated disruption of the ACL.[62] In valgus-external rotation, the skier falls forward and when the medial edge of the anterior portion of the ski engages with the snow, the skier is propelled forward, and the lower leg is abducted and externally rotated in relation to the thigh. The ski considerably magnifies this torque, acting as a lever.[62] The loading pattern of the knee ligaments in the dynamic snowplow is similar to the slip-catch mechanism, with internal rotation and valgus of the knee.[60] The most common injury mechanism before the introduction of the modern ski among recreational skiers has been Phantom Foot.[38,62] In Phantom Foot, the skier has lost balance and is lying on snow with hips below the knee. The injury occurs when the inside edge of the ski hits the snow surface, forcing the knee joint into a combination of internal rotation and valgus, which is similar to slip and catch.

Based on observations in five Canadian elite alpine ski racers, additional ACL injury mechanism was proposed by McConkey.[63] The mechanism is combined anterior shear loading on the knee from a passive external force imparted on the tibia from the ski boot (ie, BIAD) and an active internal shear force from a strong quadriceps muscle contraction that occurred as the skier attempted to recover from a back-weighted, unbalanced jump landing.

There is very limited scientific data on the neuromuscular factors that contribute to ACL injury in skiing.[64] Recent studies have revealed that skiers after ACL reconstruction may suffer significant and persistent neuromuscular deficits. [65-67] Internally developed forces from the quadriceps muscles may strain the ACL in the distal range of motion close to full knee extension, while the hamstring muscles act as an ACL synergist, producing a posteriorly directed shear moment on the tibia. [48-50] Barone et al.[68] evaluated muscle activity patterns and the kinematics of alpine ski jump landings; during their study, one of the participants suffered an ACL-injury. The injured skier demonstrated a lesser spatial change in the center of mass throughout the clap period (the time point when the tails of the skis make contact with the snow to the time point when the full length of the skis are in contact with the snow), and displayed relatively less hamstring muscle activity in the injured limb compared to the noninjured limb during the postclap period. Additionally Raschner et al.[69] in their 10-year prospective study, evaluated the relationship between physical fitness and ACL injury risk in young competitive ski racers and found that trunk (core) strength was a significant predictor of ACL injury.

2.3.2 ACL injury mechanisms in snowboarding

ACL injuries are rare among recreational snowboarders only 1-4% of injuries in snowboarders are ACL ruptures.[4,13,70] However, it has been found that when they happen, most of these injuries have occurred when only one foot was attached to the snowboard. Snowboarders usually release the back foot while riding on the ski-lift as well as on long flat traverses where they do not have enough momentum to keep moving, so the snowboarder has to kick with one foot to gather more speed.[13] With one foot firmly attached to snowboard falling can lead to valgus and external rotation.[71] Studies have shown that jumping promotes knee injuries in both recreational and professional snowboarders. [31,72-76] Fixation of both feet is assumed to protect against knee injuries, [33,36,77,78] but it is likely that this effect will be reduced as the impact energy and torsion forces increase with the higher and more spectacular jumps taken by contestants. Furthermore, most of the snowboarders have the front foot marginally rotated relative to the board, resulting in a slight internal tibial rotation of the knee and creating a posture that makes the snowboarder susceptible to suffer an ACL-injury.[71] Another ACL injury mechanism in snowboarders is the “big jump and flat landing” mechanism. These typically occur when making big jumps and flying over an inclined landing slope. It has been postulated that when the snowboarder lands on a flat landing, the quadriceps are eccentrically contracted, which can lead to increased loading on the ACL at the moment when the snowboarder hits the snow.[49] In their study, Davies et al.[49] examined snowboarders who had sustained ACL injury after a flat landing from a jump and found that snowboarders preparing for a landing exhibit more quadriceps contraction, which increases the loading force on the ACL during the landing.

2.3.3 Lower leg fracture mechanisms in skiing

The modern hour glass shaped ski that makes quick turns easier and modern SBB-systems have changed the injury pattern, especially in the knee joint and they have made tibia fractures less frequent.[79,80] With respect to equipment related factors in skiing, the SBB-system is a key injury risk factor. Lower extremity equipment related (LEER) injuries depend on SBB-systems.[81] Injuries occur when the binding fails to release and the ski acts as a lever to turn or twist the lower extremity, bending at the cuff of the boot and this generates sufficient torque to result in a bony failure.[40,82] It has been reported that the majority of lower leg injuries could have been prevented if there had been a properly functioning release function.[81,83] LEER injuries most often affect beginners and children who are most likely to have ill-fitting boots and lower quality bindings than more experienced skiers.[38,81,84] Nevertheless, despite advances in equipment design, modern ski bindings have not protected the knee from serious ligament trauma and the incidence of proximal tibia fractures has risen during the last years.[10,38,85] Bürkner et al.[83] found that in 59 % of all accidents causing lower extremity fracture, the binding had failed to open. There is an increased risk of complex fractures in the proximal or distal epiphysis if the binding does not open properly. Patton et al.[86] reported that majority of tibia fracture by skiers are caused by falls on same level (79 %) followed by collisions (13%) and jumps (8%)

2.3.4 Lower leg and ankle fracture mechanisms in snowboarding

Snowboarders with feet fixed on the board with soft boots and non-releasing bindings on board are more likely to fracture their tibia more distally than skiers because of the differences in equipment and skiers are more likely to fracture both tibia and fibula.[86] Isolated fibula fractures are suffered almost exclusively in snowboarders and it has been postulated that the hard shell boots worn by skiers protect them from these injuries.[86,87] Snowboarder's tibia fractures are more often caused by loss on of control when jumping than skier's tibia fractures.[86] Lower leg fractures sustained during snowboarding are more likely to be on the leading side; the ankle and the distal tibia is the most frequent fracture site. [71,86]

One third of the snowboarder's ankle fractures are fracture of the lateral process of the talus, which are named after the sport (snowboarders fracture). Fracture of the lateral process of the talus in snowboarders has been thought to result from sudden dorsiflexion and external rotation combined with axial loading.[88] This frequently occurs when the snowboarder lands from a height after an aerial maneuver.[89] Shear forces transmitted from the calcaneus to the lateral process of the talus can result in fracture. [89-91]

2.3.5 Head injury mechanisms

The most frequent types of mechanism in both skiing and snowboarding are falls on same level, followed by collision between users and jumps.[92,93,94] A collision with a solid obstacle causes the most serious traumatic brain injuries (TBI).[92,93] Levy et al.[94] reported that collisions with trees resulted in significantly more severe injuries than skier-on-skier collisions or simple falls.

For both snowboarders and skiers, head injuries frequently occur on the easy and middle slopes. There are some differences in the reasons behind the injury between skiers and snowboarders. Skiers are more likely to collide with stationary objects whereas due to differences in their riding stance, snowboarders are more likely to suffer backward falls with an occipital impact.[95,96] Among snowboarders, falls during jumps in terrain parks are a more frequent cause of injury than among skiers.[92,94] It has been documented in earlier studies that the types of injuries occurring following jumps are likely to be more severe in nature and more often require an ambulance transfer. [97-100]

2.3.6 Upper extremity injury mechanisms

Thumb injuries occur during falls, with the skiing pole in the hand, resulting in forced abduction and extension at the metacarpophalangeal joint.[101-104] Following thumb Ulnar collateral ligament (UCL) injuries, shoulder injuries are the second commonest injury to the upper limb in skiing. Falls on same level are the most common mechanism of shoulder injury in both skiing and snowboarding with either a direct contact with snow, axial loading from an outstretched arm, or eccentric muscle contraction associated with shoulder abduction during a fall.[105] The most common mechanism of injury to the acromioclavicular joint a direct fall on the acromion[105] whereas clavicular fractures result from downward forces acting on the shoulder as or from a direct blow to the clavicle.[105,106] Proximal humeral fractures tend to occur from a fall on an outstretched hand with axial loading along the shaft of the humerus.[106]

When a snowboarder loses balance, with both feet attached to the board unlike skiers snowboarders tries parry the fall with the hands, which is the most common wrist injury mechanism.[5,13,107]

2.3.7 Spine injury mechanisms

Loss of control while jumping is the most common injury mechanism among snowboarders whereas skiers usually suffer acute serious spinal injuries from falls or collisions at high speeds.[106,108-111] Wakahara et al.[112] reported that experts are more likely become injured while jumping than beginners. Seino et al.[113] reported that the mechanism of fracture was a backward fall from a jump and that the most common pattern was the flexion-distraction type. Nakaguchi et al.[95] demonstrated that the majority of snowboarders fall backwards; conversely, skiers tend to fall forwards. Skiers tend to suffer from more cervical spine injuries due to falling forward after losing control while skiing at excessive speeds. [95,114] In addition, landing in an uncontrolled manner after a jump may result in a direct blow to the back, resulting in a transverse or spinous process fracture in both skiers and snowboarders.[109] Collisions on the slopes also can be significant contributors to spinal injuries, especially among skiers.[109-111]

Tarazi et al.[110] noted that the majority of spinal injuries were fractures. Burst fractures are the most common patterns, with anterior dislocation of the flexion-distraction type followed by an anterior compression fracture.[75,108,110,112-115] Yamakawa et al.[75] found no significant difference between skiers and snowboarders related to the location of spinal fractures. The thoracolumbar junction is the most common site of injury, with fractures of

T12 and L1 accounting for 50% in skiers and 35% in snowboarders. Cervical injuries are most frequently seen in the lower neck, mainly involving C6 and C7.[75,108,110,112,114,115] Neurological injuries are highly associated with cervical spine injuries and subsequently less likely with thoracic followed by lumbar spine injuries.[75,108,110,112,114,115]

2.4 Epidemiology of injuries among recreational skiers and snowboarders

There have been different methods of reporting injury incidence in winter sports. In studies on recreational skiing and snowboarding, the injury incidence has been typically reported as injuries per 1000 lift tickets sold, per 1000 skier days and mean days between injury (MDBI).[6,18] The method described by Bergstrom and Ekeland has been popular, where 20 ski-lift ascents count as one skier day.[16,116]

There are a variety of studies reporting the epidemiology of skiing and snowboarding injuries from all over the world. [6,8,10-14,33,36,43,117-123] From Vermont in USA comes the most well- known, largest and still ongoing skiing research project.[18] However, there are few studies from one ski resort and with physician-assessed injured skiers. [5,18,124]

2.4.1. Injury sites

Majority of skiing and snowboarding injuries are self- inducted falls on slopes. [9,12,16,18,36,118] Fortunately collisions with another person accounts only for approximately 5-15% all injuries. [6,12,16] However, Bergström et al.[16] reported that collisions were recorded in 18% of all injuries at certain parts of the slopes. Moore et al.[125] reported that collision with another individual was independently associated with increased injury severity (ISS >= 16) as well as axial skeleton, thoracic, and renal injuries. Collisions with immovable objects account for smaller portion of injuries but are also more likely to be more serious injuries.[109-111]

TPs can be found at most of the ski resorts and since the introduction of twin-tip skis. Brooks et al.[100] concluded that the increasing number of ski areas with TPs might increase the risk for severe injuries related to jumps or other aerial maneuvers. In simple terms, more TP users mean more injuries. Brooks et al.[100] found that 27 % of all injuries occur in TPs. In Quebec, Hagel et.al[120] described an increase in injury rates that coincided with an increase in the number of ski areas where TPs were offered, suggesting an association between these sites and an increased risk of injury. In previous studies, it has been estimated that between 5% and 27% of skiing and snowboarding injuries occur in TPs[99,100] Carus et al.[126] found the injury rate in big jumps to be 2.9/1000 jumps and Major et al.[74] reported an annual injury rate of 37.8/100 athletes among WC half pipe snowboarders. Carus et al.[126] also noted that injury rates and increased odds of injury were associated with features that require a very clean technique or promote aerial manoeuvres, especially those demanding a larger drop to the ground. Furthermore, skiing and snowboarding injuries sustained in TPs are more likely to be more severe than those sustained on regular slopes.[30,98-100,127]

There are no published studies on injuries occurring in urban environment or small suburban hills, only one study examining indoor skiing exists.[22] During the last decade, urban skiing and snowboarding have become increasingly popular. In urban skiing and snowboarding, the riders try to balance on handrails and jump off buildings. Urban riding tricks are similar to riding in terrain parks with jumps and manmade obstacles, but take place in residential and industrial urban areas.

2.4.2. Differences in skiing and snowboarding injuries

There are distinct differences in the type of injuries sustained by snowboarders and skiers. The injury incidence among skiers has been around 2–3 injuries per 1000 skier days[1,4,6,10,37,122] It has been estimated that in snowboarders, the injury rate is 4–16 injuries per 1000 snowboarder days. [13,35,10,15,33,36,37] Kim et al.[13] compared snowboarding and skiing injuries over 18 seasons at a Vermont ski resort and found that the injury rate (MDBI) was 400 for snowboarders and 345 for skiers. However, most snowboarding injuries were wrist injuries and generally of the upper extremity, whereas skiers were more likely to suffer lower extremity injuries.

The severity of most injuries in both sports lies in a range from minor to moderate.

[9,116,128,129] However, participation in high-energy sports is also associated with major trauma and significant morbidity and mortality. [96,130-134,135] The most common injuries in snowboarding in descending order are head and facial, left upper limb, spine, chest and abdomen, left lower extremity, right upper extremity, and right lower extremity. [5,13,77,99,136,137] This pattern demonstrates the laterality of injury as snowboarders travel sideways and have both feet fixed to one board. It also reveals that upper body injuries are more common.[4,9,99,138,139] Fractures of the lateral process of the talus were considered rare injuries before the increase in the popularity of snowboarding. These fractures are being seen with increasing frequency in snowboarders, accounting for 32% of ankle fractures suffered by snowboarders.[140]

In comparison, the more than half ski injuries involved the lower extremities followed by head, back and shoulder injuries.[1,4,6,10,37,122] The knee has been reported as the most common site of injury, accounting for 23-27% of all skiing injuries.[1,15,37,55] Much improved binding release systems have resulted in a significant reduction in the numbers of tibia shaft fractures; The tibial shaft and ankle fracture rates have fallen to approximately 5% of all injuries in recreational skiers in more recent studies but at the same time knee injury incidence has risen.[6,18] Prior to the introduction of carving skis, complex fractures of the proximal tibia were rarely seen. Recently these fractures are being encountered more frequently in connection with skiing.[83,85,86] There is limited knowledge on tibial fracture types, location and mechanisms of injury in the literature. [86,141]

2.4.3. ACL injury incidence

Since the early 1980s, the number of anterior cruciate ligament (ACL) ruptures has increased,[8,18,142] even though some studies have reported a decrease in the risk of sustaining an ACL injury since carving skis became more popular.[40,143,144] It has been reported that anterior cruciate ligament (ACL) is still affected in about 20 % of all skiing injuries and approximately 50% of serious knee injuries.[145,146] Female recreational and competitive skiers have a doubled incidence of suffering a knee injury than their male counterparts and the ACL injury risk is 3 times greater in female skiers.[80,147,148]

ACL injuries do not seem to be so common in recreational snowboarders, ACL ruptures account for 1-4 % of all injuries.[4,11,13,70] Whereas ACL and other knee injuries are almost as common among elite/professional level snowboarders as in skiers accounting for approximately 15 % of all injuries.[72-74]

2.4.4 Lower leg fracture incidence

With the advent of modern stiff ski boots, the incidence of ankle ligamentous injuries and fractures has declined significantly since the early 1970s, with the reduction in injury rates being reported as high as 92%.[8] The tibial fracture rates have fallen to approximately 5% of all injuries in recreational skiers in more recent studies.[6,18]

Fractures of the tibial shaft account for 0.7-5 % for all snowboarding injuries[10,11,13,15] and snowboarders are more likely to injure distal tibia and ankle than skiers.[10,86,140] Kirkpatrick et al.[140] prospectively documented 3213 snowboarding injuries, of which 15% affected the ankle. The incidence of lateral process of the talus fractures was unexpectedly high, accounting for 32% of ankle fractures.

2.4.5. Head injury incidence

Estimates from numerous countries indicate that head injuries account for 9% to 19% of all injuries.[10,15,55,92,149] Head injuries are the leading cause of death in skiing and snowboarding accidents,[94,132,150] and a head injury appears to be the most frequent reason for hospital and ICU admission in this skiing and snowboarding population. [116,130,134,151] It has also been demonstrated that young men have an increased risk of head injury, especially severe TBIs; these injuries mainly occur during jumps or in high-speed crashes.[93,94,152,153]

2.4.5. Upper extremity injury incidence

Today, a skiing fall is the commonest cause of an acute UCL injury,[102] and injury to UCL of thumb is the most common upper extremity injury in skiing.[43,45,101,150,154] Following thumb injuries, shoulder injuries are the second commonest skiing-related injury to the upper limb, with incidences reported as 8% to 16% of all ski injuries.[137,155] Shoulder injuries account for 20% to 34% of injuries in snowboarders.[5,18,36,101] The commonest shoulder injuries in both skiing and snowboarding are clavicle fractures, anterior dislocations of the glenohumeral joint, rotator cuff tears, and acromioclavicular joint injuries.[6,137] Wrist injuries account for approximately 20% snowboarding injuries. [6,13,34,43,70]

2.5 Epidemiology of injuries among ski racers

There are only a few epidemiological investigations into injuries occurring in competitive alpine skiing. A Norwegian group conducted a two-year retrospective interview study[156] and methodological study[157] on World Cup level skiers and two follow-up studies.[158,159] One study conducted on Swedish ski high school students[160] and two single event studies, the Olympic Games 1994[161] and the Junior World Championship 1995[162] Haaland et al.[159] compared the injury rates before and after changes in ski regulations. Pujol et al.[163] conducted a study on the incidence of ACL injuries. The majority of these studies are based on data from the FIS Injury Surveillance System, established by FIS prior to the 2006/07 season.

There are some differences in the overall injury patterns between the ski racers and in those reported among recreational skiers.[164] Previous studies revealed that the majority, i.e. 72-83%, of ski racers have had at least one serious injury during their career.[165,166] Flørenes et al.[157] found that the injury rates over the FIS World Cup 2006-2008 were 36.7 per 100 athletes during the 5-month winter season. Bere et al.[158] reported 12.9 severe injuries (> 28 days absence) per 100 athletes. The same study reported that males had a higher overall rate of injury as well as a higher rate of time loss injury than females in training and competitions.

Among ski racers, the knee is the most commonly injured body part experiencing ACL injuries as the most frequent specific diagnosis in all previous studies.[156,167] Pujol et al.[163] data showed that elite-level alpine skiing had a very high incidence of primary ACL injury (8.5 ruptures per 100 skier-season), bilateral ACL injuries (30.5%), and re-injuries (19%). Other frequently injured body parts are in descending order; lower back, the hand, head/face and shoulder.[54,156,167,156,158,159] The most common injury types in competitive skiing have been reported to be joint and ligamentous injuries, followed by fractures/bone stress and muscle/tendons injuries[54,156,167,156,158,159]

2.6 Risk factors in recreational skiing and snowboarding

If one wishes to prevent injuries among skiers, there is a need for knowledge on injury mechanisms and an understanding of why injuries occur.[168] One common framework for undertaking injury prevention research can be found in van Mechelen's 'sequence of prevention' model.[168] Firstly, the injury epidemiology should be described by reporting the injury incidence and severity. Secondly, the risk factors and injury mechanisms need to be investigated and described. The third step is to introduce measures or prevention strategies derived from this etiological knowledge. In the fourth step, the effect of the measures or strategies should be evaluated by repeating the first step.

2.6.1 Context related risk factors

Context related risk factors for snowboard and skiing injuries include beginner's mistakes,[107,121] participation in competitive events[72,159] and suboptimal environmental conditions.[169] Even though being a beginner is a risk factor, in the majority of studies, it has been found that skiing lessons did not decrease the risk of injury.[12,119,170-172] Environmental conditions have a major effect in skiing and snowboarding injuries. It has been reported that the majority of injuries occur in the afternoon when snow conditions are often at their worse. Furthermore, weather patterns also tend to cause poor visibility and fatigue affects both performance and judgment in the afternoon.[43,169] Hasler et al.[169] noted that snowboarding on icy slopes without helmet was the most significant risk factor in snowboarding injuries.

Alcohol consumption has been associated negatively with the risk of injuries in skiing and snowboarding; not only does alcohol increase the risk of accidental injury but its use has also been linked with increased risk-taking.[173] Nonetheless, Made reported that alcohol did not appear to be a major problem in the ski slopes in northern Sweden.[5]

2.6.2 Equipment related risk factors

Practically all release bindings operate on the same basic mechanical principle: a spring-loaded cam or lever detent.[40] Bindings have an indicator that is defined by an international standard. Input data for this determination include the skier's weight, height, and age, as well as the skier type—a term for the steepness of trails normally traveled by the skier and the speed at which those trails are negotiated. The inspection and calibration of alpine ski bindings is a complex process that requires specialized tools, equipment, and a properly trained technician.[174] The release function is designed to release the ski under circumstances where the ski may act as a lever to potentially injury the tibia or knee.[38,39] Nonetheless, the current standard SBB systems are claimed not to be able to release adequately in all injury situations.[175]

Proper fitting of the equipment is necessary, especially with children.[119] Poor boot fit is a major factor leading to lower leg fractures and sprains, especially among children.[40,118]

There are several different protection devises aimed for snowboarders and skiers. Many of the protection devices are sufficient in lowering the risk of the most common injuries to the wrist, however many faults have been discovered in these wrist guards.[176] Previous reports have found an increased risk of injury to the arm and shoulder among those wearing such protection devices.[177,178]

2.6.3 Behavioural risk factors

Another risk factor is the increase in risk-taking behaviours that snow-sports and the energy drink manufacturing companies have embraced. With regard to 'poor individual responsibility/risk management, it has been claimed that skiers and snowboarders sometimes gamble with their health rather than miss an important competition or risk their place on the team; they may even take an unnecessary risk simply for the thrill of action.[153,84,179]

2.6.4 Risk factors in ski racing

In recent years, injury prevention models have been a major part of the risk management process within leading sports governing bodies, such as the FIS.[180] Due to the high-risk nature of ski racing, skier safety has been a priority for the FIS.[181] Since 2006, evidence-based research on injury prevention in competitive skiing has been conducted under the guidance and support of FIS within the FIS Injury Surveillance System. The objective of the FIS Injury Surveillance System has been to provide data on the injury rate and patterns in international skiing and snowboarding.

In alpine ski racing, the major factors that make the athletes susceptible to injuries (intrinsic and extrinsic risk factors) are still rather unclear. The intrinsic risk factors are related to the characteristics of a skier such as age, gender, body composition, previous physical fitness and psychosocial stress. Extrinsic risk factors are related to environmental variables such as discipline, skill level, exposure, slope (conditions of snow, safety measures and weather) and equipment (skis, boot and binding system and protective equipment).

2.7 Injury prevention

2.7.1 Recreational skiing and snowboarding

During recent decades, the skiing and snowboarding industry has focused its injury prevention efforts on protective gear. In order to protect both skiers and snowboarders from injury, different types of protective devices have been proposed: Mandatory helmet use, hand/arm protectors, back protectors, knee and lower-leg protectors, knee braces, and airbag systems.[164] Unfortunately their effectiveness for protection against injuries is still unclear.[182] Helmets are mandatory for competitive skiers in the FIS events in all disciplines.[72] Nonetheless, most ski resorts do not typically require helmet use. In the absence of compulsory regulations, helmet use has generally been low among recreational skiers and snowboarders although their use tends to be more common in children.[15,183] Fortunately, more recent statistics indicate that there has been increased helmet usage over the last decade, from 14–25% in the 2002–2003 skiing season to 70–87% in 2012–2013.[184] There is some controversy about the precise degree of the protective efficacy of helmets against injury but most studies do support the use of helmets for both skiers and snowboarders.[123,149,153,185,186]

A few studies have studied whether trail design and grooming hours of the slopes can influence the rate and severity of injuries. They found that injuries could be reduced by avoiding narrow passages on a slope, providing easier bypasses for beginners on the steeper parts of the slopes and making wider slopes.[16,187,188]

Furthermore we found two studies[51,189] on injury awareness which claimed that injuries could be avoided and skiing safety increased by viewing a video. In both studies, the result showed reduction of injuries in the video group.

2.7.2. Ski racing

The regulations for World Cup (WC) racing skis were changed prior to the 2012/2013 season in an attempt by FIS to reduce the risk of injuries in WC skiing.[180,190] The side cut radius and ski length were increased in all disciplines except SL, making the skis longer, straighter and less aggressive. The largest change was made in the GS ski, where the turning radius changed from 27 m to 35 m for males and from 23 m to 30 m for females. Helmet use in all disciplines is currently mandatory in all competitive disciplines by FIS. Spinal protective devices are allowed under alpine ski racing suits but their use is not currently mandatory. FIS implemented a concussion protocol in 2013. According to FIS medical guidelines, it is important that concussion is managed so that there is physical and cognitive rest until there are no remaining symptoms. Activities that require concentration and attention should be avoided until the symptoms have been absent for a minimum of 24 consecutive hours without medication that may mask the symptoms.[191]
In order to prevent ACL ruptures in skiers, the literature recommends that ACL and knee injury prevention programs should be developed for each sport and that the intervention needs to be based on each sport specific injury mechanism and specific risk factors.[192-194] Jordan et al.[64] reported that primary ACL ruptures in ski racers were typically accompanied by lateral compartment chondral lesions and complex meniscal tears. During the secondary ACL reconstruction was noted that chondral lesions and menical tears had worsened over time. [64] Given the high occurrence of ACL re-injury, [160,163,195] secondary injury prevention may be of equal importance as primary ACL injury prevention for alpine ski racers. Westin et al.[196] implemented ACL injury prevention program in Sweden, the most important finding in their study was that there was an overall 45% reduction in the numbers of ACL injuries in alpine ski students attending a Swedish ski high schools since beginning of the program.

2.8 Long term post-injury consequences

Very limited information has been published on the long-term consequences and outcome of injuries among skiers and snowboarders. There is only one observational cohort study[195] on long term outcomes after knee injury in ski racing. It reported that 33% of former ski racers had knee symptoms that substantially affected their knee-related quality of everyday life, and slight majority (52%) of those who sustained an ACL-injury had fair or poor knee scores. Dekker et al.[197] reported that women are more prone than men to experience long-term consequences of sports injuries especially with horse riding, playing soccer or skiing. A knee injury will often have difficult short-term consequences such as an interrupted skiing career. Not being able to participate in sports is known to be an important psychosocial factor,[198] which may become manifest after an absenteeism of only 3–4 weeks, let alone longer periods.[199] Nonetheless, Haida et al.[200] found that it is possible to find better performances after an ACL tear in ski racing. A major consideration is the potential for ACL tears to be associated with injuries to knee structures other than the ACL, such as the menisci and articular cartilage. It seems that alpine skiing-related ACL injury involves distinct injury patterns and elite skiers may suffer a progressive worsening in chondral lesions and meniscal tears subsequent to primary ACL reconstruction.[201-203]

The risk of knee osteoarthritis with onset at a young age, resulting in life-long sequelae, is a reality after a major knee injury.[204] Post-traumatic osteoarthritis was present in ~50% of patients at 15 years after a major knee injury, and was similarly noted in 50% of the participants in a long-term follow up study after an isolated meniscus tear and total meniscectomy.[205-207]

Proximal tibia fractures have become more common.[141] This is clinically significant, since the risk of post-traumatic sequelae is higher after tibia plateau fractures involving the weight-bearing joint surfaces compared to shaft fractures.[208] In earlier studies on tibia plateau fractures, the majority of skiers could not return to their previous level of activity.[209]For patients who were involved in competitive sports, a tibia plateau fracture can be a career ender.[210,211]

Head injuries can cause severe debilitation or even death, and also result in a high financial burden to society as well as to the affected individual. All traumatic brain injuries carry the potential to cause significant, long-lasting disabilities[212] and recurrent head impact exposure and concussions contribute to long-term neurologic sequelae.[213] As far as we are aware, there are no studies conducted on long-term neurologic sequelae in skiing or snowboarding. There is a growing concern about persisting consequences of concussion or mild traumatic brain injury in sports and there are several studies conducted on other sports with frequent head injuries that have shown that repeated concussions can exert long term effects. [213,214] Nonetheless there are an insufficient number of longitudinal studies conducted with a high-quality design.

3. AIMS OF THE STUDY

The purpose of this thesis study was to provide information on the incidences, mechanisms of injury, and nature of both recreational and competitive alpine skiing and snowboarding injuries in Finland. Also, in addition to the overall incidences and injury related circumstances, more detailed aims were focused on recreational skiing lower leg fractures in and urban skiing head injuries.

The specific aims of the study were:

1. To study the incidence, mechanisms, distribution, and severity of recreational alpine skiing and snowboarding injuries in a large and popular ski resort in Northern Finland and to compare it with injury rates around the world (I).
2. To investigate the injury patterns and rates in Finland at the competition level of alpine skiing (II).
3. To characterize alpine skiing and snowboarding related tibial fractures in order to reveal specific fracture patterns in these two different sports, and to elucidate the mechanisms of injuries behind these different patterns (III).
4. To evaluate the types and severity of traumatic brain injuries (TBI) occurring in skiing and snowboarding in suburban small hills and in the urban environment, and to assess the mechanisms of injuries resulting from these kinds of injuries (IV).

4. PATIENTS AND METHODS

4.1 Study setting and data collection

4.1.1 Study I

The first study covered six seasons (2006–2012), assessing injured recreational alpine skiers and snowboarders at the Levi Ski Resort Ltd., Finland. The Levi Ski Resort has a Ski Data® system which records automatically every ski lift run taking place, thus resulting in a reliable number of actual runs down the slopes. The Levi ski resort has first-aid patrols that consist of two paramedics. The number of patrols actually present on the slopes varies from 1-3 according to time of the year. During busy weeks, there was also a physician assisting the ski patrols on the slopes. Additionally, there are voluntary ski patrollers with some medical training. The Levi first-aid has helped injured skiers for over 20 years and has registered data on injured skiers since 1994. The Levi ski patrol encounters the injured skiers in two ways: either the person himself or herself contacts the emergency system after the injury or, in more severe cases, the injured person is evacuated from the injury scene by the response team. The emergency system has two first aid clinics located on both sides of the resort. The physicians working on site were on call when the slopes were open. They were mostly general practitioners, with some orthopaedic training. At the first aid clinic, the physician would examine the patient and register the data on a standardized written form (Appendix X) for all of the injured persons that they encounter. The task for the first aid clinic in Levi is mainly triage but some treatment is provided as well. Small wounds are sutured and splints applied on an injured limb before patients are referred to further care. The diagnosis is based on clinical findings. The questionnaires are archived in the emergency system's headquarters and it was this data that was analysed retrospectively. The data consist of injury conditions, patient characteristics, and noted and/or suspected injuries.

Skiing and snowboarding injuries were defined as any type of injury incurred during a downhill sport activity or lift transportation in persons encountered by the emergency system.

The injuries were classified according to the injured body site and the type of injury. Clavicle injuries were classified as shoulder injury. The emergency system conducts primary triage only by clinical assessment and is not able to undertake radiologic examinations.

The injury types were classified by the first aid clinic's doctors at the time of injury according eight primary triage findings: 1) contusion, 2) distortion/strain, 3) suspected fracture, 4) open fracture, 5) laceration/wound, 6) concussion, 7) unconsciousness over 10 min, and 8) dislocation. The severity of injury was classified into four categories according to the level of care needed: grade 1 injury (patient was treated by the emergency system with no need for further referral), grade 2 injury (patient was transferred to the local primacy care clinic), grade 3 injury (patient was transferred to hospital by ambulance), and grade 4 injury (patient was transferred to tertiary care by helicopter). We defined grade 1 injuries as minor, grade 2 injuries as moderate, grade 3 injuries as severe, and grade 4 injuries as critical.

The injury incidence was calculated with respect to the annual number of ski-lift runs provided by the Ski Data® system. The incidence is presented as the number of injuries divided by the number of 10,000 ski-lift runs. In addition to the observed incidence, we estimated the injury rate for 1000 skier days by using the method described by Bergstrom and Ekeland,[16] where 20 ski-lift ascents are counted as one skier day.

4.1.2 Study II

Injuries among ski racers of all ages taking place in alpine skiing competitions or training sessions in slopes in Finland were retrospectively studied. The study period was from the start of the season of 2008-2009 to the end of the season of 2009-2010. The inclusion criterion was an acute injury resulting in a training pause longer than one week in an athlete having a competitor's license registered under the national alpine ski federation (Ski Sport Finland) During the study period, each year on average 662 athletes of all ages had a Ski Sport Finland's competitor's license, even though all skiers with competitor's license were not active competitors. There was a male gender dominance (65%) compared to females (35%). Most of the active alpine ski competitors were adolescents in Finland, 82% of skiers were aged between nine and 15 years. The percentage of adults (over 15 years) was 10% and that of masters (over 35 years of age) 8%, respectively. [215]

The identification of the injured athletes, fulfilling the inclusion criteria, was conducted by repeated e-mail enquiries and personal contacts with all ski clubs, ski high schools and ski racers in Finland during the study period. The data collection was conducted directly with the athletes (or with their guardians in the case of younger persons) by personal communication and by asking them to respond to a standardized written questionnaire. (Appendix Y) We further explained the purpose and procedure of the interviews at the team captain's meetings at the beginning of the season 2010-2011, where head coaches from all ski clubs were required to be present. At these meetings, we asked the coaches to inform their athletes and the guardians about the study.

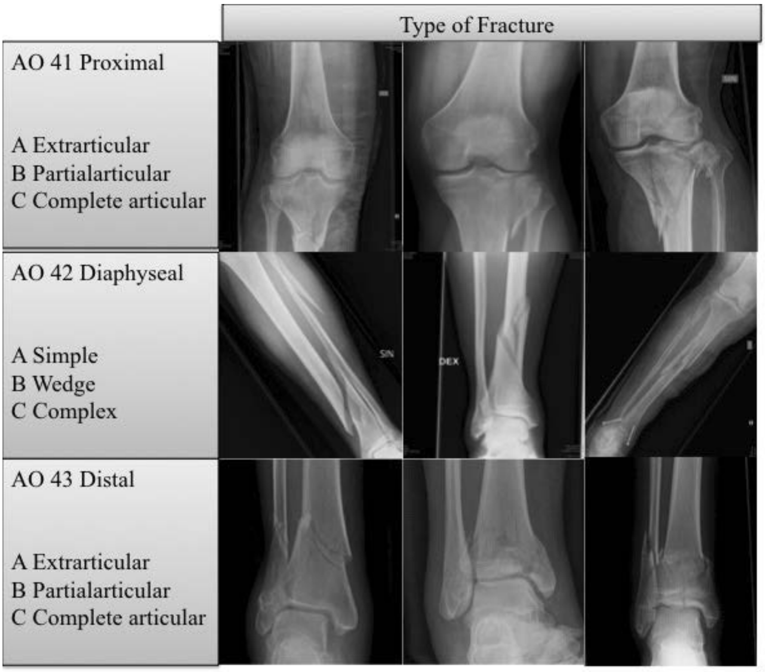
Collected data consisted of patient characteristics, mechanism of the skiing accident, use of protective gear, injuries, care provided, the length of the recovery off-ski period, and a subjective outcome at six months post-injury. The subjective outcome was assessed with a five-step scale: no, mild, moderate, major or severe (not able to ski) discomfort in skiing at six months post-injury.

4.1.3 Study III

For study III, three university Hospitals (Helsinki, Kuopio, and Oulu) and one secondary level center (Rovaniemi) collected all patients with tibial fracture (ICD-10 codes S82.1, S82.2, S82.3, excluding ankle fractures, ICD-10 codes S82.5 and S82.6) due to alpine skiing or snowboarding accident from 1 January 2006 to 31 December 2012 (six full ski seasons). Three of the hospitals were chosen on the basis of their location next to the largest ski resorts in Finland (Kuopio, Oulu and Rovaniemi). There are only small ski resorts in Helsinki area, but a high number of people originating from the city travel to larger ski resorts and if they suffer an accident, many of them will be referred to Helsinki University Hospital for further treatment. The hospital records and X-rays were reviewed retrospectively during data collection as follows; equipment in use (skis or snowboard), age (patients younger than 16 years were defined as children), gender, mechanism of injury (loss of control on same level, loss control in jump, collision with another person, collision with an immovable object, or unknown).

The authors at each institute classified tibia fractures by according to AO classification[216] in terms of finding the fracture patterns in skiers and snowboarders. In the AO classification, the anatomic location of a fracture is designated by two numbers, one for the bone and one for its segment. Each long bone has three segments: the proximal, the diaphyseal, and the distal segment. Proximal and distal fractures are divided into three subgroups (A extra-articular, B partial articular, C complex articular). In the diaphyseal segment, the subgroups are A simple, B wedge, and C complex fractures. AO groups and subgroups involve a progressively detailed description of the fracture patterns within these categories. More detailed information on the AO fracture classification in the tibia is presented in Fig 5.

Fig. 5. AO fracture classification in the tibia shaft presented by examples of plain X-rays in the study patients



4.1.4 Study IV

This study included all patients all patients referred to the Trauma Unit of Helsinki University Hospital from 2006 to 2015 with Computed Tomography (CT) assessed acute head injury (ICD-10 S06-S07) due to skiing or snowboarding accidents in Greater Helsinki (50 km radius from Helsinki). Head injuries that did not require a CT-scan or an MRI and injuries older than 24h were excluded from this study, as well the injuries taking place outside of 50 km radius from Helsinki.

There are 12 small resorts within the 50-km radius from Helsinki that generally are open from December to April. The average elevation difference in these resorts is 62.5 meters (range 30-84 meters) and a total of 33 ski lifts that transport the visitors up the hill.

For the purposes of this study, the place of injury was divided into three categories; ski resort slopes, terrain parks, and urban. Site of injury was recorded from ambulance records. Urban skiing was defined as skiing or snowboarding outside skiing resorts within streets of the cities. Hospital records were retrospectively reviewed for data collecting: equipment used (skis or snowboard), age, gender, use of helmet, site of injury, mechanism of injury, intubation, transport method, Glasgow Coma Scale / GCS motor component at admission, pupil size and reactivity, other injuries, head CT-scan finding according to Abbreviated injury score (AIS) classification (if repeated CT scans, the one 24 hours post injury was reviewed), length of stay in hospital and Glasgow Outcome Scale (GOS). Traumatic brain injury was done classification was done from CT-scans using ICD-10 and severity according to the AIS. AIS is an anatomical-based coding system to describe the severity of injuries. The score describes three aspects of the injury (type, location and severity).
AIS severity score is on a scale of one to six, one being a minor injury and six being maximal (currently untreatable). GOS is the most widely used measure for assessing global outcome following a brain injury. The scale divides into outcome categories that allow standardized descriptions of the objective degree of recovery. Patients are assigned to one of five possible outcome categories: 1) death, 2) persistent vegetative state, 3) severe disability, 4) moderate disability, and 5) good recovery.[217]

4.2 Statistical analyses

The incidence is presented as the number of injuries per 10,000 ski-lift runs. In addition, the injury rate is presented as injury per 1000 skier days and MDBI. Results are presented as means ± SD for continuous non-skewed variables. The frequency distribution of the categorical variables is compared between the groups with the Chi-square test. Student's t-test was used for testing differences in continuous variables (age). The statistically significant level is set as $p < 0.05$. Statistical program SPSS (IBM Corp. released 2009. IBM SPSS Statistics for Windows, version 13.0. Armonk, NY: IBM Corp.) was used in the analyses.

4.3 Ethical considerations

The Ethics Board of Helsinki University Central Hospital approved the study protocol. In the third multicentre study, the respective hospitals' review boards also approved the protocol. The participants in the first study were informed that they were taking part in the study on a voluntary basis, and that the information collected was to be used for medical research purposes. Informed written consent to participate was obtained from the patients in the first study. All study subjects were anonymized and patient identification was not possible.

5. RESULTS

5.1 Incidence and severity of recreational alpine skiing and snowboarding injuries in a large and popular ski resort in Northern Finland (I)

5.1.1 Patient characteristics

The mean age for the study population was 24 (range 3–82, SD ±14.0) years. The snowboarders were statistically significantly younger compared to skiers (mean age 21 (range 7-66) years vs. 24 (range 3-82) years, $p<0.05$). Injuries occurred slightly more commonly in males both in snowboarding (n=491, 55%) and in skiing (n=1135, 57%). During the 6-year study period, altogether 2911 injuries were recorded. Skiing was associated with 1991 (68 %) cases, snowboarding with 893 (31 %) cases, and other (i.e telemark, monoski, snowbikes, snowblades etc.) in 27 (1 %) cases.

5.1.2 Incidence

During the 6-year study period, there were 29,576,132 lift runs, and altogether 2911 injuries were recorded. The average injury incidence was 0.98 injuries per 10 000 lift runs (annual variation ranging from 0.82 to 1.08). Correspondingly, the average number of ski lift rides needed to generate one injury was 10,160. The estimated mean injury rate was approximately 1.97 per 1000 skier days, which makes the MDBI 508 days.

5.1.3 Injury mechanisms and injury profile

In skiers, the majority of accidents (n=1430, 72%) took place on the on-piste areas. Followed by injuries that took place in TPs (n=388, 19%), during ski-lift taxi (n=112, 6%), and in off-piste areas (n=61, 3%). The injuries were due to falling down on the same level (n=1246, 63%), loss of control during a jump (n=388, 19%), collision with another person (n=156, 8%), collision with an immovable object (n=142, 7%) and distortion without falling (n=59, 3%). Only 3 % (n=12) of the injuries due to loss of control while jumping occurred in females. In snowboarders, majority of the accidents took place in the slope on the on-piste areas (n=632, 70%), followed by accidents in TPs (n=221, 25%), during ski lift taxi (n=25, 3%), and in off-piste areas (n=15, 3%). Snowboarding injuries were attributable to falling down on the same level (n=616, 69%), loss of control during a jump (n=212, 24%), collision with an immovable object (n=26, 3%), collision with another person (n=24, 3%) and distortion without falling (n=15, 1 %).

The most common type of injury among skiers was suspected fracture (n=689, 35%) followed by distortion (n=557, 28%) and contusion (n=324, 16%) (Table 1a) Among skiers in 128 (18% of suspected fractures) the injured extremity was in malalignment and primary reduction was done at the first aid station. Also among snowboarders the most common type of injury was suspected fracture (n=486, 55%) followed by contusion (n=164, 18%) and distortion (n=101, 11%). Among snowboarders in 61 (13% of suspected fractures) the injured extremity was in malalignment and primary reduction was done at the first aid station. The detailed injury types are presented on Table 1b.

Table 1. Types of injuries and percentage of all injuries among skiers a) and snowboarders b) according to injury location

a)

Skiers

Site of injury	n	%	Site of injury	n	%
Head	**298**	**15,0%**	**Hand and wrist**	**382**	**19,2%**
Concussion	127	6,4%	Suspected fracture	285	14,3%
LOC over 10min	3	0,2%	Open fracture	1	0,1%
Laceration	158	7,9%	Contusion	54	2,7%
Suspected fracture	3	0,2%	Distorsion	10	0,5%
Contusion	7	0,4%	Laceration	9	0,5%
Neck and spine	**120**	**6,0%**	Dislocation	23	1,2%
Suspected fracture	37	1,9%	**Pelvis and Femur**	**45**	**2,3%**
Contusion	48	2,4%	Suspected fracture	24	1,2%
Distorsion	35	1,8%	Contusion	15	0,8%
Thorax and abdomen	**45**	**2,3%**	Laceration	6	0,3%
Suspected fracture	23	1,2%	**Knee**	**573**	**28,8%**
Contusion	20	1,0%	Suspected fracture	33	1,7%
Laceration	2	0,1%	Contusion	35	1,8%
Shoulder	**252**	**12,7%**	Laceration	17	0,9%
Suspected fracture	151	7,6%	Distorsion	488	24,5%
Open fracture	3	0,2%	**Lower leg**	**159**	**8,0%**
Contusion	55	2,8%	Suspected fracture	80	4,0%
Dislocation	43	2,2%	Open fracture	7	0,4%
Elbow and arm	**46**	**2,3%**	Contusion	55	2,8%
Suspected fracture	31	1,6%	Laceration	17	0,9%
Open fracture	3	0,2%	**Ankle and foot**	**69**	**3,5%**
Contusion	12	0,6%	Suspected fracture	22	1,1%
			Distortion	24	1,2%
			Contusion	23	1,2%

*In two patients injured body part could not be interpreted from questionnaires b)

Snowboarders

Site of injury	n	%	Site of injury	n	%
Head	**106**	**11,9%**	**Hand and wrist**	**359**	**40,2%**
Concussion	78	8,7%	Suspected fracture	298	33,4%
LOC over 10min	0	0,0%	Open fracture	0	0,0%
Laceration	22	2,5%	Contusion	46	5,2%
Suspected fracture	2	0,2%	Distortion	9	1,0%
Contusion	4	0,4%	Laceration	2	0,2%
Neck and spine	**81**	**9,1%**	Dislocation	4	0,4%
Suspected fracture	23	2,6%	**Pelvis and Femur**	**12**	**1,3%**
Contusion	55	6,2%	Suspected fracture	4	0,4%
Distortion	3	0,3%	Contusion	6	0,7%
Thorax and abdomen	**30**	**3,4%**	Laceration	2	0,2%
Suspected fracture	18	2,0%	**Knee**	**71**	**8,0%**
Contusion	11	1,2%	Suspected fracture	4	0,4%
Laceration	1	0,1%	Contusion	7	0,8%
Shoulder	**138**	**15,5%**	Laceration	3	0,3%
Suspected fracture	95	10,7%	Distortion	57	6,4%
Open fracture	0	0,0%	**Lower leg**	**16**	**1,8%**
Contusion	20	2,2%	Suspected fracture	3	0,3%
Dislocation	23	2,6%	Open fracture	0	0,0%
Elbow and arm	**30**	**3,4%**	Contusion	6	0,7%
Suspected fracture	24	2,7%	Laceration	7	0,8%
Open fracture	1	0,1%	**Ankle and foot**	**50**	**5,6%**
Contusion	6	0,7%	Suspected fracture	15	1,7%
			Distortion	32	3,6%
			Contusion	3	0,3%

5.1.4 Injury distribution

The detailed information on the injury distribution is presented in Table 2. In skiers, the most commonly injured body parts were the lower extremity (n=858, 43%) of the cases, the upper extremity (n=680, 34%), the head (n=298, 15%), the spinal column (n=120, 6%) and trunk (n=45, 2%) of the cases. In snowboarders, the respective figures were the lower extremity (n=149, 17%), the upper extremity (n=527, 59%), head (n=106, 12%), the spinal column (n=81, 9%) and trunk (n=30, 3%) of the cases.

Vast majority (68 %) of skiers' lower extremity injuries were knee injuries (n=573, 29% of all injuries) whereas among snowboarders' majority (61%) of upper extremity injuries were wrist injuries (n=321, 36% of all snowboarding injuries).

Table 2. Injury distribution in recreational skiing (n=1991) and snowboarding (n=893). Percentage of all injuries in presented in parenthesis

	All injuries					
	Head	Neck	Thorax	Spine	Upper extremity	Lower extremity
Ski	298 (15%)	15 (1%)	45 (2%)	105 (5%)	680 (34%)	858 (43%)
Snowboard	106 (12%)	4 (1%)	30 (3%)	77 (8%)	527 (59%)	149 (17%)

5.1.5 Injury Severity

The ski-patrol evacuated 720 (36%) injured skiers and 280 (31%) injured snowboarders from the slopes. The most common reason for referring the patient to further care was the need for X-ray in grade 2 patients, and a major fracture or its suspicion in grade 3 patients, respectively. During the study period of six years, four skiers and one snowboarder needed to be transferred to hospital by helicopter (critical injury) due to a major head injury. The emergency system encountered nine fatalities during the study period, but they were all attributable to a pre-existing medical condition. Out of the skiing injuries (n=4, 0.3%) were classified as critical (n=292, 15%) as severe, (n=880, 44%) as moderate and (n=815, 41%) as minor. In snowboarding, the corresponding numbers were (n=1, 0.1%), (n=115, 13%), (n=469, 53%) and (n=308, 34%) respectively. Skiers and snowboarders who had become injured due to a loss of control while jumping in TPs were more likely to suffer a critical or severe injury than those who suffered collision injuries or fell on the same level (n=134, 22%, n=83, 14% and n=196, 9%, $p < 0,05$)

Table 3. Distribution on severe and critical injuries among recreational skiers and snowboarders. Percentage of all injuries is presented in parenthesis

	Severe and critical injuries					
	Head	Neck	Thorax	Spine	Upper extremity	Lower extremity
Ski	31 (1.5 %)	5 (0.3 %)	5 (0.3%)	31 (12%)	89 (5%)	135 (7%)
Snowboard	14 (1%)	3 (0.3%)	7 (0.7%)	21 (2%)	58 (6%)	13 (1%)

5.2 Injury rates and patterns in Finland at the competition level of alpine skiing (II)

5.2.1 Injury number and patient characteristics

There were 61 injuries (36 male and 25 female) fulfilling the inclusion criteria during the study period (26 injuries in the season of 2008-2009 and 35 in the season of 2009-2010). The mean age of the injured females was 14 (range 10-36, SD±3.46) years; this was identical in the males (i.e. 14 years; range 9-30 years). The majority of accidents occurred during the winter-snow months from November to May. Only a few (n=4, 7%) injuries took place in summer glacier training camps.

5.2.2 Injury mechanisms and injury profile

The most common mechanisms of injury were falling down on the same level (n=31, 50 %), collision in an on-piste area (n=18, 30%), loss of control while jumping (n=5, 8%), collision in an off-piste area (n=5, 8%) and distortion without falling (n=2, 4 %). Most of the injuries took place in GS (n=34, 56%) followed by SL injuries (n=19, 31%) and SG injuries (n=8, 13%). (Table 4)

The most common injury was fracture (n=32, 52%) followed by ligament injuries (19, 31%), contusions (n=5, 8%), concussions (n=4 7%), and dislocations (n=1, 2%). There were no lethal injuries during the study period. Nearly all upper extremity injuries were fractures, only one being a glenohumeral dislocation.

Table 4. Mechanism of injury in different disciplines

	Fall on level	Collision on course	Collision off course	Jump	Distortion	Total
Slalom	10	8			1	19
Giant Slalom	18	8	5	2	1	34
Super G	3	2		3		8
Total	31	18	5	5	2	61

The lower extremity was the most commonly injured body area (n=39, 64%), 21 of were being knee injuries and 16 were lower leg (tibia and fibula) fractures. Eight of the knee injuries were ACL injuries. All ACL injuries and lower leg fractures were treated surgically. Two ankle sprains among females were recorded.

Seventeen (28%) injuries were in the upper extremity and there were four head injuries (7 %). The most common upper extremity injury was a fracture in the hand (including fingers). The incidence of upper extremity and hand injuries was similar between males and females. There was also one abdominal injury. The detailed information of the injured body area is presented in table 5.

Table 5. Injury locations and types among ski racers in Finland

Injury location	Number of injuries	Fracture	Dislocation	Ligament injury	Contusion	Concussion
Head	4					4
Torso	1				1	
Collarbone	2	2				
GH-joint	1		1			
Humerus	2	2				
Antebrachium	3	3				
Hand	9	9				
Knee	21			17	4	
Lower leg	16	16				
Ankle	2			2		
Total	61	32	1	19	5	4

5.2.4 Injury Severity

Fifty-two (85%) of the injuries required hospital admission with the median length of hospital stay of one day (range 1-21 days). The most common reason for admission was surgical operation (n=28), non-operative management of the injury (n=20), and post-commotion survey after a head trauma (n=4). Only one operation was carried out due to an abdominal parenchymal injury. All other operations were due to injuries to the extremities. Three of the operations were performed on the upper and 24 on the lower extremities. Two athletes gave up their career after sustaining the injury, but only one retirement was purely due to the injury (lower leg fracture) preventing alpine skiing at a competition level.

Almost all (n=14, 88%) skiers with a lower leg fracture and all skiers with the ACL injury sustained greater than mild discomfort in skiing at six months after the injury. The average length of the recovery off-ski period was 175 days (range 150-180 days) after the ACL injury and 115 days (range 95-180 days) after the lower leg fracture. None of the skiers with an upper extremity injury were experiencing greater than mild discomfort while skiing six months after the injury. The average length of recovery off-ski period was 51 days (range 7-120 days).

5.3 Tibial fractures in recreational skiing and snowboarding in Finland

5.3.1 Patient characteristics

There were 372 skiing or snowboarding related tibial fractures (342 in skiers and 30 in snowboarders, respectively) in 363 patients. Nine patients had more than one fracture at regio (AO) 41–43. One child on skis suffered two tibial fractures on two different occasions on the same tibia. The mean age of the study population was 22 (range 3-69, SD ±16.1) years. There was a male dominance in the study population (n=238, 78%). Almost half of the patients were under 16 years old (n=162, 45%). The mean age among injured skiers was younger than that of the snowboarders (22 vs. 25 years $p<0.05$).

5.3.2 Injury mechanisms

In skiers, the most common injury mechanism was falling on the same level (n=244, 71%). Snowboarders, on the other hand, were more likely to become injured due to losing control when jumping (n=14, 47%, vs. n=22, 6% for skiers, $p<0.05$). Detailed information on the injury mechanism is presented in Table 6. Snowboarders who suffered a tibia fracture due to loss of control when jumping were likely to suffer an AO type C tibia fracture (n=5, 16% of all fractures $p=0.13$). There were no significant differences or correlation in mechanism of injury and fracture patterns between adult skiers and children.

Table 6. Injury mechanisms among skiers and snowboarders. Adult skiers n= 192, Adult snowboard n=18, Skier children n=150 and snowboard children n=12

	Fall (%)	Collision with person (%)	Collision with object (%)	Jump (%)
Ski adult*	75	7	9	6
SB adult	17	6	22	55
Ski children	67	16	10	7
SB children	32	9	9	50

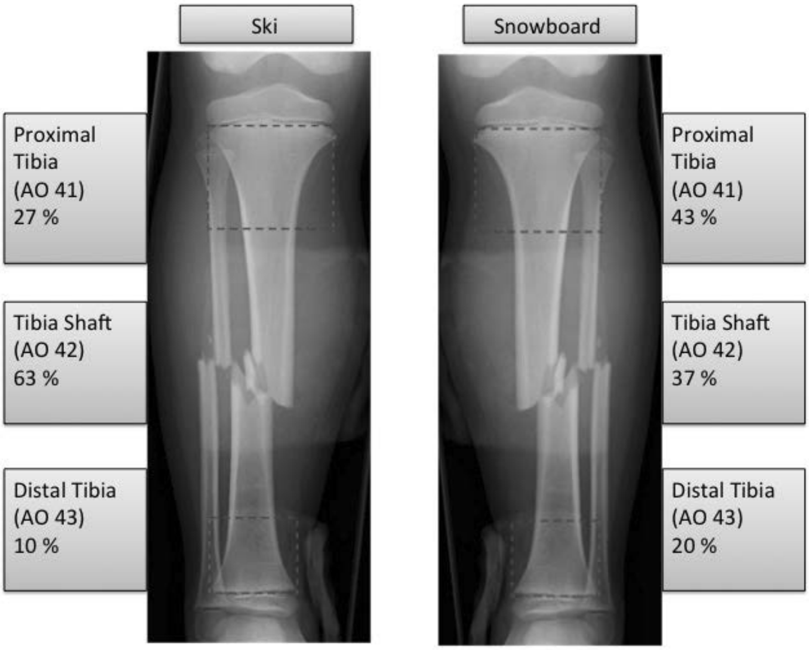
*injury mechanism was unknown in 6 (3%) patients

5.3.3 Injury profile

Thirty-eight (11%) fractures were open among skiers and five (17%) among snowboarders. Adult skiers were more likely to suffer an open fracture than children (n=25, 17% vs. n=13, 7%, $p<0.05$). Only one child among the snowboarders suffered an open fracture.

Tibia shaft fracture (AO 42) was the most common fracture site among skiers with (n=215, 63%) fractures, followed by proximal tibia fractures (AO 41) (n=92, 27%) and distal tibial fractures (AO 43) (n=35, 10%). Snowboarders were most likely to suffer, either a proximal tibial fracture (n=13, 43%) or a tibial shaft fracture (n=11, 37%), the third most common injury types were distal tibia fractures (n=6, 20%).

Figure 6. Fracture location in percentage in skiers and snowboarders



In both skiers and snowboarders, the spiral diaphysis fracture was the most common fracture type in children. The incidence of proximal tibia fractures was significantly higher in adult skiers than in children (n=61, 49%, vs. n=31, 16% $p<0.05$). The prevalence of distal tibia fractures was identical among adult and children skiers (n=20, 10% vs. n=15, 10% $p>0.05$). Snowboarding children did not suffer any distal tibia fractures. There were no significant gender-specific differences in the fracture location.

Figure 7. Fracture location in percentage in skiing adults, snowboarder adults, skiing children and snowboarder children

5.3.3.1 Proximal tibia fracture (AO-41) profiles

Type B proximal tibial fractures (n=41, 45%) were the most common proximal fracture type among skiers followed by type A (n=30, 32%) and type C (n=21, 23%). Snowboarders were most likely to suffer type A (n=6, 46%) followed by type B (n=4, 31%) and type C (n=3, 23%). The incidence of intra-articular tibial fractures (type B and C) was significantly higher in adult skiers than in children (n=55, 36%, vs. n=7, 4%, $p<0.05$). More detailed information on the fracture distribution is presented in Figure 8.

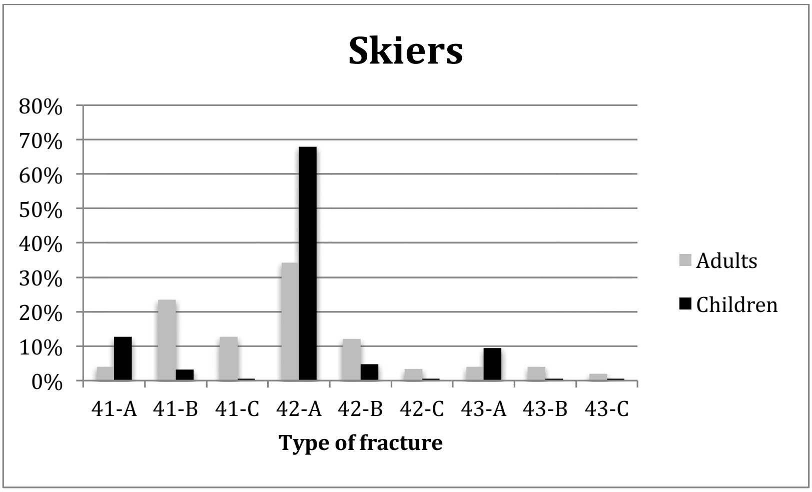
5.3.3.2 Tibial shaft fracture (AO-42) profiles

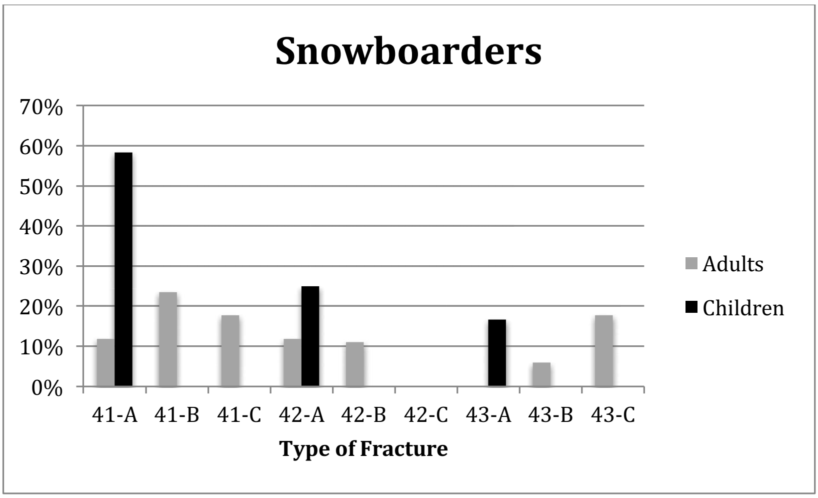
Type A tibial shaft fracture (n=180, 84%) was the most common fracture type among skiers and snowboarders (n=8, 73%). The incidence of more complex type B and C fractures was higher in adult skiers than in children (n=25, 15%, vs. n=10, 5 %, $p<0.05$). There were no significant differences between adult and children snowboarders.

5.3.3.3 Distal tibial fracture (AO 43) profiles

Type A distal tibial fractures (n=22, 63%) were the most common fracture type among skiers followed by intra-articular type B (n=9, 25%) and type C (n=4, 12%). Snowboarders were most likely to suffer type C (n=4, 67%) followed by type B (n=2, 33%). The incidence of intra-articular tibial fractures (type C and B) was higher in adult skiers than in children (n=9, 7%, vs. n=4, 2%, $p<0.05$). Snowboarding children did not suffer any intra-articular distal tibial fractures.

Figure 8. Fracture location (proximal = 41, shaft = 42, distal = 43) and type (Proximal and distal fractures are divided into three subgroups A extra-articular, B partial articular, C complex articular. In the diaphyseal segment, the subgroups are A simple, B wedge, and C complex fractures) distribution in percentage in skiers and snowboarders.





5.4 Head injuries in urban environment skiing and snowboarding; a retrospective study on injury severity and injury mechanisms. (IV)

5.4.1 Patient characteristics

There were 72 skiing or snowboarding related head injuries (53 in skiers and 19 in snowboarders, respectively). The mean age in the study population was 26 (range 12-45, SD ±10.05) years. Nine of the skiers were paediatric patients (under 16 years old). There were no significant differences in type of injury, injury mechanism or outcome between paediatric patients and adults. There was a male dominance in the study population (n=60, 83%). A slight majority (n=39, 54%) of the patients had not been wearing a helmet. Helmet usage was not known in 8 patients. Skiers were more likely to wear a helmet than snowboarders (n=21, 46% vs. n=4, 22%, p=0.03).

5.4.2 Injury mechanisms and injury profile

Among skiers, head injuries were due to loss of control during a jump (n=23, 43%), falling down on the same level (n=16, 30%), collision with another person (n=7, 13%), and collision with an immovable object (n=4, 8%). Three (6%) patients were injured after a major fall (over 3 meters) while trying to balance on a handrail. Snowboarding injuries were due to loss of control in the jump (n=10, 52%), falling down on the same level (n=6, 32%), collision with an immovable object (n=2, 11%), and collision with another person (n=1, 5%). More detailed information on the injury profile and helmet usage is presented in Table 7.

Table 7. The type of head injuries according to helmet use and discipline in 72 patients suffering ski or snowboard related TBIs.

	Helmet		**Discipline**		
Type of injury	**Yes (n=25)**	**No (n=39)**	**SB n=19**	**Ski n=53**	**Total (%)**
Concussion	14	31	18	33	**51 (70)**
Traumatic cerebral edema	2	2	0	4	**4 (6)**
Diffuse traumatic brain injury	2	1	0	4	**4 (6)**
Focal traumatic brain injury	1	2	0	3	**3 (4)**
Epidural hemorrhage	0	0	0	1	**1 (1)**
Traumatic subdural hemorrhage	6	3	1	8	**9 (13)**

5.4.3 Injury severity

There were two fatal injuries due to head trauma. One patient was struck by a snow groomer and had an initial GCS of 3. This patient underwent endotracheal intubation at the scene, was transported by helicopter to the hospital, and admitted to the ICU, where the patient subsequently died secondary to a severe subdural haemorrhage. The other patient collided with an immovable object in a terrain park, arrived at the accident and emergency department with an absent pulse, a GCS of 3, and fixed and dilated pupils. Neither of these two patients was wearing a helmet.

Seventy-one percent (n=51) of the patients had isolated head injuries in the absence of other associated trauma. The most common associated trauma was injuries to extremities, which were present in 10 (14%) patients followed by neck injuries among 7 patients (10%). Four patients (6%) had more than three associated injuries (neck, thorax and extremities).

Fifty-four percent (n=39) of the patients had a primary GCS below 15 on the scene and 38% (n=27) on admission to hospital. Eleven patients (15%) had a GCS score below nine on the scene but only eight patients had a GCS score below nine on admission. Eighteen percent (n=13) of the patients had a decreased GCS motor component on admission and that was more likely due to have taken place in terrain parks and on the urban environment compared to ski slope injuries (n=9, 23% vs. n=4 12%; $p < 0.05$). Head CT revealed according to the AIS classification that, majority of the injuries (n=51, 70%) minor injuries (AIS 1), (n=4, 7%) moderate (AIS 2), (n=6, 8%) serious (AIS 3), (n=5, 7%) severe (AIS 4), and (n=6, 8%) had critical (AIS 5). There were no statistically significant differences in mean head AIS values between the accident sites.

Table 8. Head injury outcomes in 72 patients suffering ski or snowboard related TBIs. Values are given as medians, range in parenthesis

	Helmet		**Discipline**		
Characteristic and outcome	**Yes (n=25)**	**No (n=39)**	**SB n=19**	**Ski n=53**	**Total**
GSC on scene (median)	15 (5-15)	15 (3-15)	15 (10-15)	13 (3-15)	**15(3-15)**
GCS motor component on admission (median)	6 (2-6)	6 (1-6)	6 (6)	6 (1-6)	**6 (1-6)**
Hospital LOS in days (median)	1 (1-24)	1 (1-14)	1 (1)	1 (1-24)	**1 (1-24)**
ICU LOS in days (median)	0 (0-6)	0 (0-6)	0 (0)	0 (0-6)	**0 (0-6)**
GOS (median)	5 (3-5)	5 (1-5)	5 (5)	5 (1-5)	**5 (1-5)**

The mean length of stay in hospital was 2.95 (SD ±2.96, range 1-24 days) days for the whole study population. A total of 17 (24%) patients were admitted to ICU (mean length of stay 2.82 days, SD ±1.81, range 1-6 days). Patients who became injured in TPs and on streets were more likely to be admitted to ICU than patients injured on slopes (n=14, 32% vs. n=3, 10%, $p<0.05$) In the comparison of those not wearing a helmet with those wearing one, there were no statistically significant differences in the incidence of hospitalization (n=11, 48% vs. n=12, 28%; $p > 0.05$) or in ICU admission (n=8, 32% vs. n=8, 20%; $p > 0.05$).

Based on the GOS score at discharge, (n=57, 78%) were classified as having made a good recovery from the injury (GOS 5), (n=9, 13%) had a moderate disability (GOS 4), (n=4, 5%) had a severe disability (GOS 3), and (n=2, 3%) died (GOS 1). No patients remained in a persistent vegetative state. Majority of the patients (n=64, 89 %) were discharged to home. Two patients (3%) were stepped down to other hospitals for further care. Both patients had suffered traumatic subdural haemorrhage and spinal injury to lumbar spine. Four patients (6%) were transferred to rehabilitation facilities. Three of these four patients had suffered traumatic subdural haemorrhage and one patient had epidural haemorrhage and multiple facial fractures. We could not find statistically significant differences in those with a significantly reduced GOS (less than 5) regarding the use of helmet or no helmet (n=10, 25% vs. n=4, 10%; $p > 0.05$). There were no statistically significant differences in decreased GOS values between the accident sites – TP n=9, 33%, urban n=1, 8% and slopes n=3, 10 %, $p > 0.05$.

Table 9. Outcomes of head injuries regarding helmet use and place of injury.

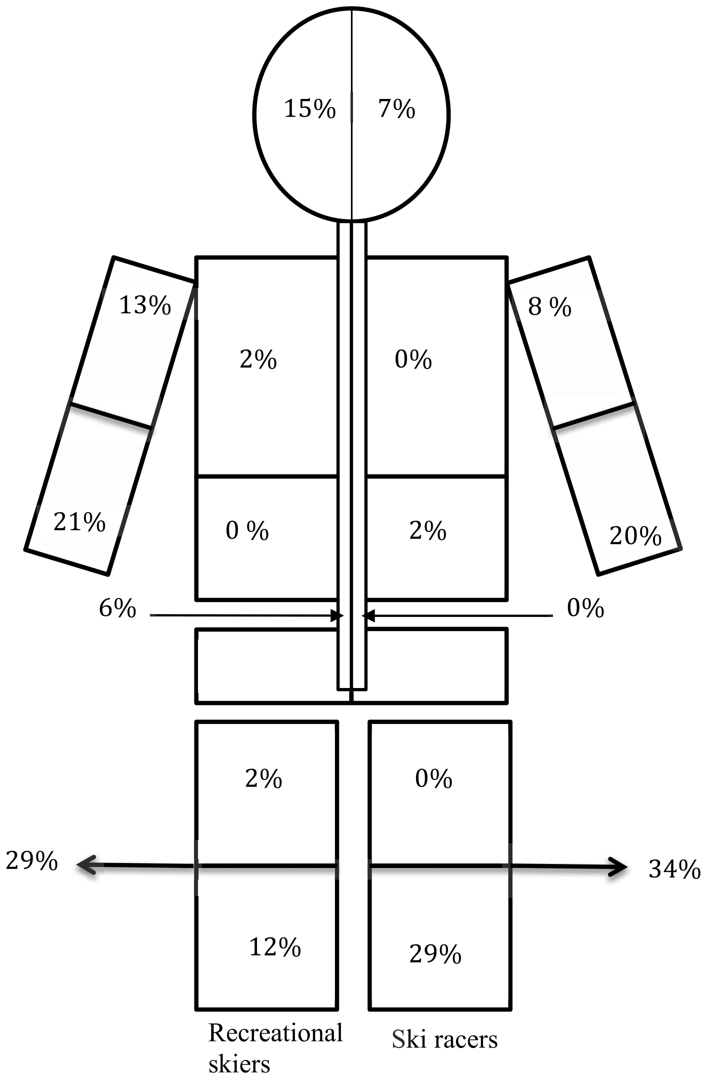
	All patients			Helmet			
	Slope (n=29)	**Terrain park (n=28)**	**Urban (n=15)**	**Yes (n=25)**	**No (n=39)**	**Unknown (n=8)**	**Tota l**
Outcome							
Hospitalization	6	12	6	12	11	1	**24**
ICU Admission	3	8	6	8	8	1	**17**
Craniotomy	1	1	1	2	0	1	**3**
GOS <5	5	9	1	10	4	1	**15**
Fatality	1	1	0	0	2	0	**2**
Discharged to home	96%	82%	87%	84%	92%	88%	**89%**

5.5 Overall injury burden among Finnish skiers and snowboarders

5.5.1 Injury distribution

There were some differences in the injury distributions between ski racers and recreational skiers and snowboarders. Recreational skiers and snowboarders were more likely to suffer from a head injury (n=298, 15% and n=106, 12% vs. n=4, 7%, $p<0.05$) whereas ski racers were more likely to suffer from a lower leg fracture (n=16, 26 % vs. n=87, 4% and n=3 0.3%). There were no statistically significant differences in the upper extremity injury incidence between ski racers and recreational skiers but snowboarders were more likely to suffer from an upper extremity injury than ski racers and recreational skiers (n=525, 59% vs. n=680, 32% and n=17, 28%, $p<0.05$). The number of spine and trunk injuries was low among all slope users. More detailed information on injury distribution on ski racers and recreational skiers is presented in Fig 9.

Fig 9. Injury distribution in percentage in recreational skiers (left), ski racers (right).



5.5.2 Mechanism of injury

A fall on the same level (n= 2168, 64%) was the most common injury mechanism in the whole study population followed by a loss of control while jumping (n=667, 20%). There were some differences in injury mechanisms: Ski racers did not suffer any injuries due to a collision with another person. Snowboarders and recreational skiers who suffered head injury, were most likely to injure themselves while jumping. More detailed information is presented in table 11. Ski racers were more likely to suffer an injury due a collision with an object than any other study group.

Table 11. Injury mechanisms presented in percentages. Ski= recreational skiers, SB= recreational snowboarders.

	Fall on same level	**Collision with another**	**Collision with object**	**Jump/fall over 3m**	**Distorsion without falling**
Ski n=1991	63% (1246)	8 % (156)	7% (142)	19% (388)	3% (59)
Snowboard n=893	69% (616)	3 % (24)	3 %(26)	24% (212)	1% (15)
Ski Racers n=61	50% (31)		38% (23)	8% (5)	4% (2)
Ski Tibia n=342*	71% (244)	12% (38)	9% (32)	6% (22)	
SB Tibia n=30	30% (9)	10% (3)	13% (4)	47% (14)	
Ski Head n=53	30% (16)	13% (7)	8% (4)	49% (26)	
SB Head n=19	32% (6)	5% (1)	11% (2)	52% (10)	
Total n=3389	64% (2168)	7% (229)	7% (233)	20% (677)	2% (76)

**Injury mechanism was unknown in 6 skiers*

6. DISCUSSION

6.1 Incidence and severity of recreational alpine skiing and snowboarding injuries

6.1.1 Overall injury rate among recreational skiers and snowboarders

We found the average injury incidence among recreational skiers and snowboarders to be 1 (0.98) injury per 10 000 lift runs or 1.9 for 1000 skier days. Earlier studies done in the USA and continental Europe[8-14] have reported higher rates (2.7-3.7) but previous Nordic studies have reported similar figures (1.2-2.2).[1,2,5,15,16] It has been speculated that Nordic inhabitants are more experienced skiers than American and European skiers, which could be one of the reasons for lower injury rates in the Nordic countries. Ski resorts in Finland are smaller with fewer steep slopes compared to North American and European resorts. In addition, most of the Finnish ski resorts are well groomed and use artificial snow makers to makes the slopes safer for the skiers.[16]

In our data most of the recreational skiers and snowboarders injuries were due to falls on the same level on slopes but we found that injuries taking place in TPs were more likely to be severe in nature and more often required an ambulance transfer. Similar results have been found in earlier studies.[76,98-100] During the last decade, many resorts have built even larger jumps and other obstacles and this appears to have increased the risk and/or severity of injuries.[13,76,99,126] The most likely reason for the more severe injuries in TPs is the development of snowboarding and park skiing into competitive sports in a direction towards more extreme performance and riskier jumps. Unfortunately, in our study we could not determine injury incidences for those who became injured in terrain parks. The SKIDATA® system records only lift rides and Levi Resort does not record actual number of runs on TPs. Although a wide variety of demographic and environmental characteristics were collected, a few important confounders were not available from the ski patrol records, such as the manoeuvre being attempted on the feature (inverted jumps) or the size of the feature or the speed at the time of impact. Big jumps, which demand a larger drop to the ground and a higher speed at the time of impact, are more likely to increase the likelihood of fracture or more serious injury.[98,126]

6.1.2 Lower extremity injuries among recreational skiers and snowboarders

The most common recreational ski injuries involved the lower extremities. Knee injuries were the most frequent type of injury among skiers; snowboarders sustained fewer lower limb injuries than skiers. Once again, similar results have been found in earlier studies.[2,6,13,33,150] Knee injuries and especially anterior cruciate ligament injuries are a major concern. It appears to be difficult to prevent knee injuries due to the fact that even relatively low twisting forces can result in significant ligament and cartilage injury.[17] The risk of sustaining a severe knee sprain increased by 240% between the 1970s and 1990s[18] even though the SBB-systems evolved most during that period. The problem seems to be that ski bindings have been designed to protect the tibia, not the knee.

6.1.3 Upper extremity injuries among recreational skiers and snowboarders

In this study, snowboarders were more likely than skiers to sustain upper extremity injuries which is in agreement with earlier studies.[2,6,17,33,137] The high number of wrist injuries is alarming (36% of all snowboarding injuries), suggesting that further prevention is needed. There is some evidence that using wrist guards can be beneficial,[178,218,219] but more information is needed on preventive measures suitable for the snowboarders. There are no standards for wrist guards and published studies have investigated a variety of different wrist guard designs so one cannot conclude that all wrist guards are protective.[13,178,218,219]

Injuries to thumb consisted only 7 % of all injuries among skiers where as humerus injuries (10 %) and wrist injuries (9 %) were more common. In previous studies UCL of thumb is the most common upper extremity injury in skiing.[43,45,101,154] We can only speculate that skiers have become more aware of the skiers thumb injuries in Finland and try to avoid falling on outstretched thumb while wearing ski poles.

6.1.4 Head injuries among recreational skiers and snowboarders

Head injuries consisted of 15% of all injuries among skiers and 12% among snowboarders. It was not possible to determine reliably whether helmet use (or non-use) was associated with this type of injury because of poor documentation within the collected data. At present Levi ski resort do not require that helmets must be worn, but now would be an opportune moment to highlight the possibility of making helmets compulsory.

The most frequent types of mechanism in both skiing and snowboarding were falls on same level, followed by jumps and collision between users and obstacles. But both skiers' and snowboarders' severe injuries were most likely to be caused by jumps and collisions. All critical head injuries were caused by collisions with solid obstacles. This is in accordance with earlier studies.[92,94 99,100,127,220]

6.2 Injury patterns and rates in Finland among ski racers

6.2.1 Overall injury rate among ski racers

There were some differences in the overall injury patterns between the present study conducted among ski racers and in those reported among recreational skiers.[8-10,13,79 104]We observed fewer hand and head injuries, but the number of the lower leg fractures was higher. The low number of head injuries compared to recreational skiers can be explained by both the mandatory use of protective helmets in ski racing as well as by the decreased risk of colliding with another skier as there is only one skier on the course at one time, most unlike the crowded slopes in recreational skiing.[16,94,149] There were also some differences between the previous studies conducted on ski racing.[156,159-162] The number of lower leg fractures was significantly higher and number of head and spine injuries was lower.[156,159] In our study, most of the ski racers were adolescents and not competing in the maximum speed discipline (DH), which is clearly reflected in the present results. Flørenes et al.[157] reported that the highest incidence was found for DH followed by SG and GS, while the incidence was lowest in slalom. In summary, the higher the speed and the bigger jumps, the higher the risk of major head, thoracic, abdominal or spinal injuries. Flørenes et al[157] found that the injury rates over the FIS World Cup 2006-2008 were 36.7 per 100 athletes during the 5-month winter season. Haaland et al.[159] stated that there had been a reduction in the injury rate (22.8 per 100 athletes during the 2013-2014 season) after the introduction of new ski regulations. The injury rate for elite alpine skiers seems to be significantly higher than in our study, even though we did not count exact injury incidences.

6.2.2 Knee injuries among ski racers

Several studies have shown that the knee [8-10,13,79,104] is the most commonly injured body part among adult recreational skiers and ski racers.[47,73,159,160] We also found the knee to be the most commonly injured body part among Finnish ski racers, accounting for 26% of all injuries. An ACL injury was the most commonly reported specific diagnosis, accounting for 50% of knee injuries. Pujol et al.[163] reported an alarmingly high frequency of ACL injuries (8.5 ruptures per 100 skier-seasons) among top-ranked French alpine skiers during a 25-year period. Among the world's top 30 athletes, 50% of elite ski racers had suffered at least 1 ACL injury.[163] Studies among adolescent ski racers have revealed a 15% ACL-rupture incidence,[69,160] which is closer to our results.

Jordan et al.[64] noted that majority of the ACL injuries among ski racers were combined injuries with typically accompanied by lateral compartment chondral lesions and complex meniscal tears and medial collateral injury. The percentage of complex meniscal tears among ski racers is also higher than in recreational alpine skiers, where the reported prevalence is less than 10%.[221,222] Unfortunately in our study more specific documentation was unavailable regarding more detailed surgical reports on meniscal tears and chondral lesions.

6.2.3 Lower leg fractures among ski racers

Lower leg fractures comprised one quarter of all of the injuries in our study, thus being more common than would have been expected based on previous reports: Lower leg injuries, which included also Achilles tendon, represented 11% of all injuries among WC skiers.[156] However, the mean age of the patients sustaining a fracture in our study was only 14 years, and 82% of all patients were under 16 years of age. The risk of a tibia fracture has been reported to be four times higher for a child than for an adult.[223] In addition, there also is a possibility of inadequately functioning SBB-system resulting from inadequate high binding release values among adolescent ski racers in Finland. Furthermore, the study period covered only two seasons, which is a relatively short period. Statistical bias due to the relatively short study period of two years in our study appears to be the most likely explanation. Interestingly, in a Swedish study[160] conducted on high school students, 44% skiers had suffered at least one injury of the lower leg either before or during the 5 year study period. The reasons accounting for the alarmingly high number of lower leg injuries among Finnish and Swedish adolescents remain unclear.

6.3 Recreational alpine skiing and snowboarding related lower leg fractures

This study indicates that the most common lower leg fracture type in skiing is still the shaft fracture and the most common mechanism is a fall on the same level. The most important finding in this study was that the number of the fractures involving tibia plateau among adult skiers is higher than in earlier studies conducted before introduction of the modern ski.[1,2,5,6,18,19] The introduction of the shorter carving ski may have changed the distribution of injuries, making proximal tibia fractures more common. Paralleling the rise in numbers of ligamentous knee injuries, the rise in proximal tibia fracture probably reflects the same phenomenon, namely the modern ski increases the forces being transmitted to the knee.[44,144,101]

6.3.1 Tibia fracture differences between skiers and snowboarders

We found differences in injury mechanism and fracture type between skiers and snowboarders: Snowboarders were more likely to experience fractures due to loss of control while jumping. There was also a difference in the distributions of lower extremity injuries between snowboarders and skiers, with ankle and knee injuries being more common among snowboarders, whereas the shaft and proximal tibia injuries predominated among skiers. These differences in injury profile between skiers and snowboarders are likely attributable to the riding stance; snowboarders have both feet fixed onto a board, which limits the amount of torsion of their lower extremities. The proximal tibia fractures also comprised almost half of the fractures in snowboarders, a value that is higher than described for recreational snowboarders in previous reports, but at the same level with elite snowboarders.[13,70,72,74,86] Complex proximal fractures have been associated with high energy and axial pressure with rotational forces[224] such as occur in jumping. It may be argued that recreational snowboarders' level of riding is relatively high in Finland, resulting in increased risk-taking behaviour with more complex jump attempts. It has been assumed that the fixed binding should protect the knees from torsional forces.[33,78] It is possible that this protective effect will be reduced in bigger jumps as the impact energy and torsion forces increase with the more complex and higher jumps that include spinning; this may be the reason accounting for the proximal tibia fractures noted in our study.

6.3.2 Lower leg fractures in children

We observed more than half of the tibia fractures in children (under 16 years). In our study, over 90% of tibia shaft fractures among paediatric skiers were simple type A fractures, suggesting that tibia shaft fractures in children occurred as a result of lower energy trauma than among adult skiers or snowboarders. Bürkner et al.[83] reported that young or inexperienced skiers suffer primarily from fractures of the tibia diaphysis. With increasing skiing experience, the injury pattern expands to cover the whole lower leg. Furthermore, our finding of a low number of open fractures in children is support for the hypothesis that the tibia fractures suffered by children are probably due to lower energy trauma.

6.4 Types and severity of traumatic brain injuries on small hills and urban environment skiing and snowboarding

Even though head injuries comprise only 3–15% of all injuries in skiers and snowboarders, it appears that the incidence of TBI is increasing.[10,92,220,225] The reason for this phenomenon is still unknown. In a Canadian study[43] on serious injuries on ski slopes (ISS greater than 12), TBI was the most common injury observed among both snowboarders and skiers. It is estimated that head injuries are the cause of 59-88% of fatalities in skiing and snowboarding related incidents.[132,133,226] In this study, we found that even on very small slopes and in urban environments, head injuries from skiing and snowboarding accidents can be serious, even fatal. The skiers and snowboarders injured in terrain parks or on streets had more severe head injuries than those occurring on slopes.

In this study, the majority (70%) of the head injuries were concussions but 24% of all injuries were serious to critical according to AIS classification. The proportion of serious head injuries was higher than in previous studies.[94,96] This study was conducted at a tertiary level hospital where the most seriously injured patients are referred. For this reason, our results represent only a fraction of the total number of ski-related head injuries in southern Finland and for this same reason; it was impossible to estimate incidences. For the same reason it was also impossible estimate the protectiveness of helmets therefor no conclusions on helmet use and injury outcome should not be drawn based on this study.

The majority of patients with head injuries (79%) enjoyed a good outcome as measured by GOS. However, 13% of the patients suffered a moderate disability at discharge. Studies of ski-related head injuries in Switzerland[130,131] and USA[97] have reported that

68% and 79% of patients respectively left the hospital with a GOS value of 5. The mortality rate, including pre-hospital mortality, was 3% in this study population, which is consistent with earlier studies.[94,97,226]

6.4.1 Helmet use among skiers and snowboarders

Because of the small study population and the lack of a control group, we could not estimate the protective efficacy of helmets. In our study population, it was noteworthy that all snowboarders who suffered a head injury either in TPs or in urban environments were not wearing a helmet. The reason behind this result is unknown - it is possible that it is a statistical anomaly due to the small study population. It is also possible that helmet wearing among snowboarders is not considered trendy or it is felt unnecessary when snowboarding on a small hill or on the streets. In our data, helmet users had worse GOS but there was no statistical significance due to the small study population.

Even though there is some controversy about the precise level of efficacy of helmets in protecting against injury,[123,149,153,184-186] it has been recommended that all participants in snow sports should wear a helmet to reduce the incidence and severity of head injury.[149,151,185,227] We speculate that the doubts of their efficacy stem from the fact that many of those injuries in terrain parks and on the street are occurring at such a high level of energy that they exceed the protection conferred by a helmet. Skiers and snowboarders may not be aware of the fact that helmets are only designed to protect people from an impact speed between 18 and 23 km/h, or falls from up to 2.4 m.[228] Previous research has recorded average skiing speeds of 40–48 km/h among recreational skiers and snowboarders[152,229,230] and speeds of up to 150 km/h in ski racers. Those speeds are clearly beyond the specifications of the helmets. Steenstrup et al.[231] analysed 4 video recordings on head injuries in freestyle skiers and snowboarders and found that the estimated preimpact velocity exceeded the current helmet impact requirements. Thus, even the best available helmets would not provide sufficient protection at these kinds of speeds. Nonetheless, we strongly believe that helmets can protect against head injuries especially in terrain parks and in urban riding on stairs and concrete instead of snow. We also highlight the importance of proper terrain park design and terrain park maintenance to reduce the risk of injuries. Urban environments are not designed for skiing or snowboarding even though many of the riders think that they are; education and risk awareness should be emphasized even though it is at odds with today's risk-taking culture that snow sports and the energy drink industries have embraced and advocated.

6.5 Limitations of the study

The major limitation of the study I was the inability to differentiate between skiers and snowboarders and males and females, because the SkiData® system does not register the sex or used equipment of the user. It was not possible to differentiate between skiers and snowboarders on their actual injury incidences with the present method even though the approach does provide the possibility to evaluate exact injury incidence (injuries/lift rides). We could only present the overall total injury incidence for both groups. It seems that there is no system in use that registers lift users' age, sex, or equipment. A major shortcoming of the first study was that we were not able to examine the injured skiers' X-rays, only the emergency system personnel's description of the injury. Diagnosis was based on the first aid doctor's clinical examination. The task for the first aid clinic in Levi's triage and the exact diagnosis is therefore perhaps unreliable due to lack of X-ray. Also, it is likely that all injuries were not included in the data, since some of the less injured mobile patients may have not contacted the ski resort emergency system but have sought for medical help after returning home or one of the 2 local privately own health care clinics. This was not obviously the case with the severe injuries, which needed evacuation and acute attention at the ski resort. The distance to the nearest hospital is far (168 km), the injured have no alternative choices when injured and impaired, than to see the first aid doctor. This makes it presumable that the material is homogeneous and the drop- outs are low with small variations.

The retrospective nature and the relatively small number of patients in study II was the major limitation. The low number of patients may also result in bias; thus, it is more sensible to draw conclusions based on the tendencies rather on absolute numbers. The relatively low number of certain injuries makes the statistical comparisons prone to bias and even impossible in some cases. There is the possibility of a type II error when interpreting the results in this study. Another limitation is that we are not able to guarantee that all patients with injuries were included in the study due to the retrospective nature of the study. It cannot be ruled out that some minor injuries fulfilling the inclusion criteria might have gone unreported due to their relatively benign nature; the athletes may have either forgotten some of the injuries they have suffered during the previous seasons and/or were not willing to report on them. Consequently, the present data does not represent the solid national epidemiology as such, but it gives a fair overall picture of the presentation of the injuries among alpine ski racers, mainly juniors, in Finland.

The study III had several limitations. The retrospective nature is the most prominent one. Due to the retrospective setting, we were unable to assess the exact injury mechanism (the speed or release of bindings etc.). It was also impossible to survey the degree of soft tissue injury or open fractures grading in reliable way, thus we had to leave that information out. Due to the retrospective setting, classification to skiers and snowboarders' skill levels was impossible. There is also a possibility of interobserver bias between assessments on fracture classification done in different hospitals by different authors. The relatively small number of snowboarders results in decreased reliability when drawing conclusions. However, the nature of snowboarding with tendency of performing several different jumping tricks supports our findings of tibial fractures taking place in these attempts

The major limitation of the study IV was the retrospectivity of the study and the small study population. Also, it is likely that all injuries were not included in the data, since some of the less injured patients have sought for medical assistance at other hospitals introducing selection bias. Helsinki University Hospital is a tertiary level hospital where the most seriously injured patients are referred. This study examined only those individuals who had sustained the more severe trauma and were triaged to have a head CT-scan done. Therefore, it was impossible to count for incidence of head injuries or the protectiveness of helmets therefor no conclusions on helmet use and injury outcome shouldn’t been drawn based on this study. Statistical analysis was difficult due to small number of patients, which makes type II error possible.

Inconsistencies regarding coding with poor interobserver reliability of the AIS system have been a matter of debate for a long time. The observer had specifically been trained by a certified AIS coder for this study, However, he did not benefit from a long-lasting coding experience which can lead to a bias. Although a wide variety of demographic and environmental characteristics were collected, important confounders were not available from hospital records, such as the manoeuvre being attempted on the feature (inverted jumps) or the size of the feature or the speed at the time of impact. Repeated head CT were not done routinely for every patient, but only in cases when the patient’s condition deteriorates during hospital admission or when the initial CT was showing injury that may need surgery if intracranial injury should extend. Thus, decision of repeated head CT is done individually in every case. This may cause some minor bias in grading the initial injury according to CT scans, since there is a possibility that initial extend of the injury can slightly increase during 24 hours even the clinical condition of the patient remains unchanged. Which, naturally, will not be detected if no routine control of 24 h CT is done.

6.6 Implications for injury prevention and future studies

Injury prevention in TPs should focus on decreasing the injury risk and severity by identifying ways to build safer jumps without sacrificing the fun/thrill of the sport. We conclude in general that proper terrain park design with safety nets, signs, and adequate grooming of the jumps and landings can reduce the risk of injuries.

It is important to design TPs with the progression system in mind. Resorts should build training parks with smaller features to allow skill building prior to exposure to the more dangerous and larger features.

Prevention of collisions between ski racers and recreational skiers also needs to be stressed; training and racing areas must always be securely marked and separated. When setting courses, coaches should take into consideration that course should have proper safety net positions, visibility and large enough “spill zones”.

Before the beginning of each ski season, we recommended that all skiers should have their equipment inspected by shop technicians who are familiar with boot sizing and binding calibrating.

Urban environments are not designed for skiing or snowboarding but when performing tricks on stairs or close to standing stationary objects, we strongly recommend the use of helmets.

The retrospective two-year pilot study among ski racers formed the basis for a continuous alpine ski injury survey in Finland. The results from the present thesis revealed a large number of knee injuries and lower leg fractures in adolescent ski racers. This reveals the need for future research within this field. There is a possibility that some Finnish ski racers are wearing a poorly functioning SSB-system leading to inadequate high binding release values. Furthermore, it is possible that adolescent ski racers start to use more aggressive adult equipment too early. Adult skis have higher torsional stiffness than skies designed for teenagers,[175] [57]which might be a contributing factor in ACL and lower leg injuries. Adolescent’s skis torsional stiffness and binding adjustments should be controlled and it would be interesting to determine whether there is a correlation between these parameters and the numbers of lower leg injuries and ACL injuries. The next step would be to introduce measures or prevention strategies and then to evaluate their effectiveness in repeat studies.

Westin et al.[196] were able to reduce number of ACL with prevention program in Sweden. This indicates that ACL-injury prevention programs should be implemented in all ski clubs and ski high schools also in Finland and the results investigated in the future.

The increasing numbers of tibia plateau fractures highlight the need for future research within this field especially since the exact injury mechanisms are still unclear. This would need continuous injury surveillance by all hospitals and ski patrollers ensuring that they provide a good description of injury mechanism, used equipment and information of whether the equipment was a proper fit.

7. CONCLUSIONS

In the four studies, the following results were noted:

1. The overall injury incidence among recreational skiers and snowboarders in Finland is lower than in previous studies conducted in the United States and continental Europe, but similar to that in published studies from other Nordic countries. A knee injury is the most common injury in skiing and wrist injury is the most common injury suffered in snowboarding.
2. The high number of lower leg fractures among ski racers is alarming. A continuous and careful monitoring of injuries needs to be established to assess this trend.
3. There are differences in the tibia fracture patterns between snowboarding and skiing; the most common fracture type in skiers was a spiral tibia shaft fracture whereas proximal tibia fractures were most common in snowboarders. The number of the intra-articular fractures to the proximal tibia among adult skiers and snowboarders was higher than literature supports.
4. Head injuries occurring in small suburban hills and in urban environments can be serious and potentially fatal. The profile and severity of skiing injuries in urban environments and small, suburban hills is comparable to those on alpine terrain

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9. REFERENCES

1. Sahlin Y. Alpine skiing injuries. *British Journal of Sports Medicine*. 1989;23(4):241-244. doi:10.1136/bjsm.23.4.241.

2. Paloneva J. Snowboarding and alpine skiing injuries in Finland *Suomen Lääkärilehti*. 2005;vsk 60(6/2005 vsk 60):s.655-s.659.

3. Made C. Alpine ski sport injuries in Swedish Lapland. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2009;9(6):386-391. doi:10.1007/s001670100229.

4. Ekeland A, Sulheim S, Rodven A. Injury Rates and Injury Types in Alpine Skiing, Telemarking, and Snowboarding. *Journal of ASTM International*. 2005;2(5):1-9. doi:10.1520/JAI12526.

5. Made C, Elmqvist L-G. A 10-year study of snowboard injuries in Lapland Sweden. *Scand J Med Sci Sports*. 2004;14(2):128-133. doi:10.1111/j.1600-0838.2003.00342.x.

6. Ekeland A, Rødven A. Injury Trends in Norwegian Ski Resorts in the 10 Year Period 1996–2006. *Journal of ASTM International*. 2008;5(6):1-8. doi:10.1520/JAI101620.

7. Ogden JA, Ganey TM, Hill JD, Jaakkola JI. Sever's injury: a stress fracture of the immature calcaneal metaphysis. *Journal of Pediatric Orthopaedics*. 2004;24(5):488-492.

8. Pope RJ. Trends in skiing injuries Analysis of a 6-year study (1972 to 1978). *Am J Sports Med*. 1980;8(2):106-113. doi:10.1177/036354658000800209.

9. Wasden CC, McIntosh SE, Keith DS, McCowan C. An Analysis of Skiing and Snowboarding Injuries on Utah Slopes. *The Journal of Trauma: Injury, Infection, and Critical Care*. 2009;67(5):1022-1026. doi:10.1097/TA.0b013e3181b0d559.

10. Davidson TM, Laliotis AT. Alpine skiing injuries. A nine-year study. *West J Med*. 1996;164(4):310-314.

11. Rust DA, Gilmore CJ, Treme G. Injury patterns at a large Western United States ski resort with and without snowboarders: the Taos experience. *Am J Sports Med*. 2013;41(3):652-656. doi:10.1177/0363546512472045.

12. Langran M, Selvaraj S. Snow sports injuries in Scotland: a case-control study. *Br J Sports Med*. 2002;36(2):135-140. doi:10.1136/bjsm.36.2.135.

13. Kim S, Endres NK, Johnson RJ, Ettlinger CF, Shealy JE. Snowboarding Injuries. *Am J Sports Med*. 2012;40(4):770-776. doi:10.1177/0363546511433279.

14. Bianchi G, Brügger O, Niemann S. Skiing and Snowboarding in Switzerland: Trends in Injury and Fatality Rates Over Time. In: *Snow Sports Trauma and Safety*. Vol 20. Cham: Springer International Publishing; 2017:29-39. doi:10.1007/978-3-319-52755-0_3.

15. Ekeland A, Sulheim S, Rodven A. Injury Rates and Injury Types in Alpine Skiing, Telemarking, and Snowboarding. *Journal of ASTM International*. 2005;2(5):12526. doi:10.1520/JAI12526.

16. Bergstrøm KA, Ekeland A. Effect of trail design and grooming on the incidence of injuries at alpine ski areas. *British Journal of Sports Medicine*. 2004;38(3):264-268. doi:10.1136/bjsm.2002.000270.

17. Patrick E, Cooper JG, Daniels J. Changes in Skiing and Snowboarding Injury Epidemiology and Attitudes to Safety in Big Sky, Montana, USA: A Comparison of 2 Cross-sectional Studies in 1996 and 2013. *Orthop J Sports Med*. 2015;3(6):2325967115588280. doi:10.1177/2325967115588280.

18. Johnson RJ, Ettlinger CF, Shealy JE. Update on Injury Trends in Alpine Skiing. *Journal of ASTM International*. 2008;5(10):1-12. doi:10.1520/JAI102046.

19. Asikainen P, Lüthje P, Järvinen M, Avikainen V, Koskinen I. Downhill skiing injuries and their cost at a Finnish skiing area. *Scandinavian Journal of Medicine & Science in Sports*. 1991;1(4):228-231. doi:10.1111/j.1600-0838.1991.tb00301.x.

20. Brukner P, Khan K. *Clinical Sports Medicine Third Revised Edition*. McGraw-Hill Book Company Australia; 2010.

21. Mustapić M, Borić I, Lepur D, Zadravec D, Visković K. Sever's disease complicated with osteomyelitis. *Acta Clin Croat*. 2014;53(2):252-255.

22. Van Laarhoven SN, Latten G, de Loos E, van Hemert W, Vles GF. Annual trauma load of the world's largest indoor skiing center. *Eur J Trauma Emerg Surg*. 2017;43(2):233-237. doi:10.1007/s00068-016-0631-3.

23. Hulkko A, Orava S. Diagnosis and treatment of delayed and non-union stress fractures in athletes. *Ann Chir Gynaecol*. 1991;80(2):177-184.

24. Valovich McLeod TC, Decoster LC, Loud KJ, et al. National Athletic Trainers' Association position statement: prevention of pediatric overuse injuries. In: Vol 46. National Athletic Trainers' Association, Inc; 2011:206-220. doi:10.4085/1062-6050-46.2.206.

25. Helsingin yliopisto HTFHKJTTLK, universitet H, fakulteten H, et al. *Alppihiihdon Alkutaival : Pujottelu- Ja Tunturihiihto Suomessa 1920-Luvulta 1960-Luvulle*. omakustanne; 2010.

26. ammattikorkeakoulu R, ammattikorkeakoulu L. *Sallan Hiihtokeskuksen Historia 1930-Luvulta Vuoteen 2010*. Rovaniemen ammattikorkeakoulu; 2011.

27. Fianet tilastot 2006-2015. Ski.fi.

28. Oestreich AE, Bhojwani N. Stress fractures of ankle and wrist in childhood: nature and frequency. *Pediatr Radiol*. 2010;40(8):1387-1389. doi:10.1007/s00247-010-1577-y.

29. FIS. The International Ski Competition Rules.

30. Langran M. *Injuries in Terrain/Fun Parks*. Online at http://www. ski-injury. com/terrainparks (...; 2011.

31. Moffat C, McIntosh S, Bringhurst J, Danenhauer K, Gilmore N, Hopkins CL. Terrain park injuries. *West J Emerg Med*. 2009;10(4):257-262.

32. Lewis A. **The hazards of urban skiing** *BBC News*. 26 February 2014

33. Abu-Laban RB. Snowboarding injuries: an analysis and comparison with alpine skiing injuries. *Canadian Medical Association Journal*. 1991;145(9):1097-1103.

34. Shealy JE, Sundman PD. Snowboarding Injuries on Alpine Slopes. In: *Skiing Trauma and Safety: Seventh International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1989:75–75–7. doi:10.1520/STP19456S.

35. Sacco DE, Sartorelli DH, Vane DW. Evaluation of Alpine Skiing and Snowboarding Injury in a Northeastern State. *The Journal of Trauma: Injury, Infection, and Critical Care*. 1998;44(4):654-659. doi:10.1097/00005373-199804000-00016.

36. Bladin C, Giddings P, Robinson M. Australian snowboard injury data base study. *Am J Sports Med*. 2016;21(5):701-704. doi:10.1177/036354659302100511.

37. Sherry E, Fenelon L. Trends in skiing injury type and rates in Australia. A review of 22,261 injuries over 27 years in the Snowy Mountains. *Med J Aust*. 1991;155(8):513-515.

38. Natri A, Beynnon BD, Ettlinger CF, Johnson RJ, Shealy JE. Alpine Ski Bindings and Injuries. *Sports Medicine*. 1999;28(1):35-48. doi:10.2165/00007256-199928010-00004.

39. Shealy JE, Ettlinger CF, Johnson RJ. What Do We Know About Ski Injury Research that Relates Binding Function to Knee and Lower Leg Injuries? In: *Skiing Trauma and Safety: Fourteenth Volume*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 2003:36–36–17. doi:10.1520/STP10960S.

40. Ettlinger CF, Johnson RJ, Shealy J. Functional and Release Characteristics of Alpine Ski Equipment. In: *Skiing Trauma and Safety: Sixteenth Volume*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 2006:65–65–10. doi:10.1520/STP39659S.

41. Balance and alignment tips on skis. October 2009.

42. Köhne G, Kusche H, Schaller C, Gutsfeld P. Ski accidents – changes since introduction of carving ski. *Sports Orthopaedics and Traumatology*. 2007;0(0):63-67. doi:10.1016/j.orthtr.2007.01.014.

43. McBeth PB, Ball CG, Mulloy RH, Kirkpatrick AW. Alpine ski and snowboarding traumatic injuries: incidence, injury patterns, and risk factors for 10 years. *The American Journal of Surgery*. 2009;197(5):560-564.

44. Muller E, Schwameder H. Biomechanical aspects of new techniques in alpine skiing and ski-jumping. *Journal of Sports Sciences*. 2003;21(9):679-692. doi:10.1080/0264041031000140284.

45. Koehle MS, Lloyd-Smith R, Taunton JE. Alpine Ski Injuries and Their Prevention. *Sports Medicine*. 2002;32(12):785-793. doi:10.2165/00007256-200232120-00003.

46. Ackery A, Hagel BE, Provvidenza C, Tator CH. An international review of head and spinal cord injuries in alpine skiing and snowboarding. *Injury Prevention*. 2007;13(6):368-375. doi:10.1136/ip.2007.017285.

47. Bere T, Florenes TW, Krosshaug T, et al. A systematic video analysis of 69 injury cases in World Cup alpine skiing. *Scandinavian Journal of Medicine & Science in Sports*. 2014;24(4):667-677. doi:10.1111/sms.12038.

48. Hame SL, Oakes DA, Markolf KL. Injury to the Anterior Cruciate Ligament during Alpine Skiing. *Am J Sports Med*. 2017;30(4):537-540. doi:10.1177/03635465020300041301.

49. Davies H, Tietjens B, Van Sterkenburg M, Mehgan A. Anterior cruciate ligament injuries in snowboarders: a quadriceps-induced injury. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2009;17(9):1048-1051. doi:10.1007/s00167-008-0695-7.

50. Demorat G, Weinhold P, Blackburn T, Chudik S, Garrett W. Aggressive Quadriceps Loading Can Induce Noncontact Anterior Cruciate Ligament Injury. *Am J Sports Med*. 2017;32(2):477-483. doi:10.1177/0363546503258928.

51. Ettlinger CF, Johnson RJ, Shealy JE. A Method to Help Reduce the Risk of Serious Knee Sprains Incurred in Alpine Skiing. *Am J Sports Med*. 2016;23(5):531-537. doi:10.1177/036354659502300503.

52. Herzog W, Read L. Anterior Cruciate Ligament Forces in Alpine Skiing. *Journal of Applied Biomechanics*. 1993;9(4):260-278. doi:10.1123/jab.9.4.260.

53. Read L, Herzog W. External Loading at the Knee Joint for Landing Movements in Alpine Skiing. *International Journal of Sport Biomechanics*. 1992;8(1):62-80. doi:10.1123/ijsb.8.1.62.

54. Herzog W, Read LJ. Lines of action and moment arms of the major force-carrying structures crossing the human knee joint. *Journal of Anatomy*. 1993;182 (Pt 2)(Pt 2):213-230. doi:10.1111/(ISSN)1469-7580.

55. Shealy JE, Geyer LH, Hayden R. Epidemiology of Ski Injuries: Effect of Method of Skill Acquisition and Release Binding Accident Rates. *Human Factors: The Journal of the Human Factors and Ergonomics Society*. 1974;16(5):459-473. doi:10.1177/001872087401600504.

56. Johnson SC. Anterior cruciate ligament injury in elite Alpine competitors. *Medicine & Science in Sports & Exercise*. 1995;27(3):323-327.

57. Bere T, Flørenes TW, Krosshaug T, Nordsletten L, Bahr R. Events leading to anterior cruciate ligament injury in World Cup Alpine

Skiing: a systematic video analysis of 20 cases. *British Journal of Sports Medicine*. 2011;45(16):1294-1302. doi:10.1136/bjsports-2011-090517.

58. Eberle R, Heinrich D, Kaps P, Oberguggenberger M, Nachbauer W. Effect of ski boot rear stiffness (SBRS) on maximal ACL force during injury prone landing movements in alpine ski racing: A study with a musculoskeletal simulation model. *Journal of Sports Sciences*. 2016;35(12):1125-1133. doi:10.1080/02640414.2016.1211309.

59. Corner TP. ACL Injuries in Skiers. 2015.

60. Bere T, Flørenes TW, Krosshaug T, et al. Mechanisms of anterior cruciate ligament injury in World Cup alpine skiing: a systematic video analysis of 20 cases. *Am J Sports Med*. 2011;39(7):1421-1429. doi:10.1177/0363546511405147.

61. Myklebust G, Steffen K. Anterior Cruciate Ligament Injuries: Prevention Strategies. In: Doral MN, Karlsson J, eds. *Sports Injuries*. Berlin, Heidelberg: Springer Berlin Heidelberg; 2014:1-13. doi:10.1007/978-3-642-36801-1_82-1.

62. Järvinen M, Natri A, Laurila S, Kannus P. Mechanisms of anterior cruciate ligament ruptures in skiing. *Knee Surgery, Sports Traumatology, Arthroscopy*. 1994;2(4):224-228. doi:10.1007/BF01845592.

63. McConkey JP. Anterior cruciate ligament rupture in skiing. *Am J Sports Med*. 2016;14(2):160-164. doi:10.1177/036354658601400213.

64. Jordan MJ, Aagaard P, Herzog W. Anterior cruciate ligament injury/reinjury in alpine ski racing: a narrative review. *Open Access Journal of Sports Medicine*. 2017;8:71-83. doi:10.2147/OAJSM.S106699.

65. Jordan MJ, Aagaard P, Herzog W. Asymmetry and Thigh Muscle Coactivity in Fatigued Anterior Cruciate Ligament-Reconstructed Elite Skiers. *Medicine & Science in Sports & Exercise*. 2017;49(1):11-20.

66. Jordan MJ, Aagaard P, Herzog W. Rapid hamstrings/quadriceps strength in ACL-reconstructed elite alpine ski racers. *Medicine & Science in Sports & …*. 2015.

67. Jordan MJ, Aagaard P, Herzog W. Lower limb asymmetry in mechanical muscle function: A comparison between ski racers with

and without ACL reconstruction. *Scandinavian Journal of Medicine & Science in Sports*. 2015;25(3):e301-e309. doi:10.1111/sms.12314.

68. Barone M, Senner V, Schaff P. ACL Injury Mechanism in Alpine Skiing: Analysis of an Accidental ACL Rupture. In: *Skiing Trauma and Safety: Twelfth Volume*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1999:63–63–19. doi:10.1520/STP12358S.

69. Raschner C, Platzer H-P, Patterson C, Werner I, Huber R, Hildebrandt C. The relationship between ACL injuries and physical fitness in young competitive ski racers: a 10-year longitudinal study. *British Journal of Sports Medicine*. 2012;46(15):bjsports–2012–091050–1071. doi:10.1136/bjsports-2012-091050.

70. Hedges K. Snowboarding injuries: an analysis and comparison with alpine skiing injuries. *Canadian Medical Association Journal*. 1992;146(7):1146-1148.

71. Mahmood B, Duggal N. Lower extremity injuries in snowboarders. *Am J Orthop (Belle Mead NJ)*. 2014;43(11):502-505.

72. Torjussen J, Bahr R. Injuries among elite snowboarders (FIS Snowboard World Cup). *British Journal of Sports Medicine*. 2006;40(3):230-234. doi:10.1136/bjsm.2005.021329.

73. Florenes TW, Nordsletten L, Heir S, Bahr R. Injuries among World Cup ski and snowboard athletes. *Scandinavian Journal of Medicine & Science in Sports*. 2012;22(1):58-66. doi:10.1111/j.1600-0838.2010.01147.x.

74. Major DH, Steenstrup SE, Bere T, Bahr R, Nordsletten L. Injury rate and injury pattern among elite World Cup snowboarders: a 6-year cohort study. *Br J Sports Med*. 2014;48(1):18-22. doi:10.1136/bjsports-2013-092573.

75. Yamakawa H, Murase S, Sakai H, et al. Spinal Injuries in Snowboarders: Risk of Jumping as an Integral Part of Snowboarding. *Journal of Trauma and Acute Care Surgery*. 2001;50(6):1101.

76. Russell K, Meeuwisse W, Nettel-Aguirre A, et al. Characteristics of injuries sustained by snowboarders in a terrain park. *Clin J Sport Med*. 2013;23(3):172-177. doi:10.1097/JSM.0b013e31827bd918.

77. Yamagami T, Ishihara H, Kimura T. Clinical features of snowboarding injuries. *J Orthop Sci*. 2004;9(3):225-229.

doi:10.1007/s00776-004-0776-5.

78. Sutherland AG, Holmes JD, Myers S. Differing injury patterns in snowboarding and alpine skiing. *Injury*. 1996;27(6):423-425.

79. Burtscher M, Gatterer H, Flatz M, et al. Effects of Modern Ski Equipment on the Overall Injury Rate and the Pattern of Injury Location in Alpine Skiing. *Clin J Sport Med*. 2008;18(4):355-357. doi:10.1097/MJT.0b013e31815fd0fe.

80. Ruedl G, Webhofer M, Linortner I, et al. ACL Injury Mechanisms and Related Factors in Male and Female Carving Skiers: A Retrospective Study. *International Journal of Sports Medicine*. 2011;32(10):801-806. doi:10.1055/s-0031-1279719.

81. Ekeland A, Holtmoen A, Lystad H. Lower extremity equipment-related injuries in alpine recreational skiers. *Am J Sports Med*. 1993;21(2):201-205. doi:10.1177/036354659302100207.

82. Natri A, Beynnon BD, Ettlinger CF, Johnson RJ, Shealy JE. Alpine ski bindings and injuries. Current findings. *Sports Medicine*. 1999;28(1):35-48.

83. A B, HP S. [Fractures of the lower extremity in skiing - the influence of ski boots and injury pattern]. *Sportverletz Sportschaden*. 2008;22(4):207-212. doi:10.1055/s-2008-1027947.

84. Scott MD, Buller DB, Andersen PA, et al. Testing the risk compensation hypothesis for safety helmets in alpine skiing and snowboarding. *Injury Prevention*. 2007;13(3):173-177. doi:10.1136/ip.2006.014142.

85. R P, U S, M W, et al. [Proximal tibial fractures sustained during alpine skiing - incidence and risk factors]. *Sportverletz Sportschaden*. 2013;27(4):207-211. doi:10.1055/s-0033-1356108.

86. Patton A, Bourne J, Theis J-C. Patterns of lower limb fractures sustained during snowsports in Otago, New Zealand. *N Z Med J*. 2010;123(1316):20-25.

87. O'Neill DF, McGlone MR. Injury risk in first-time snowboarders versus first-time skiers. *Am J Sports Med*. 1999;27(1):94-97. doi:10.1177/03635465990270012301.

88. Boon AJ, Smith J, Zobitz ME, Amrami KM. Snowboarder's Talus Fracture. *Am J Sports Med*. 2016;29(3):333-338. doi:10.1177/03635465010290031401.

89. McCrory P, Bladin C. Fractures of the lateral process of the talus: a clinical review. "Snowboarder's ankle". *Clin J Sport Med*. 1996;6(2):124-128.

90. Knoch von F, Reckord U, Knoch von M, Sommer C. Fracture of the lateral process of the talus in snowboarders. *Journal of Bone and Joint Surgery - British Volume*. 2007;89(6):772-777. doi:10.1302/0301-620X.89B6.18813.

91. Kramer IF, Brouwers L, Brink PRG, Poeze M. Snowboarders' ankle. *BMJ Case Rep*. 2014;2014(oct29 1):bcr2014204220-bcr2014204220. doi:10.1136/bcr-2014-204220.

92. Fukuda O, Takaba M, Saito T, Endo S. Head injuries in snowboarders compared with head injuries in skiers. A prospective analysis of 1076 patients from 1994 to 1999 in Niigata, Japan. *Am J Sports Med*. 2001;29(4):437-440.

93. Bailly N, Afquir S, Laporte J-D, et al. Analysis of Injury Mechanisms in Head Injuries in Skiers and Snowboarders. *Medicine & Science in Sports & Exercise*. August 2016:1. doi:10.1249/MSS.0000000000001078.

94. Levy AS, Hawkes AP, Hemminger LM, Knight S. An Analysis of Head Injuries among Skiers and Snowboarders. *The Journal of Trauma: Injury, Infection, and Critical Care*. 2002;53(4):695-704. doi:10.1097/00005373-200210000-00013.

95. Nakaguchi H, Fujimaki T, Ueki K, Takahashi M, Yoshida H, Kirino T. Snowboard head injury: prospective study in Chino, Nagano, for two seasons from 1995 to 1997. *J Trauma*. 1999;46(6):1066-1069.

96. Diamond PT, Gale SD, Denkhaus HK. Head injuries in skiers: an analysis of injury severity and outcome. *Brain Injury*. 2001;15(5):429-434. doi:10.1080/02699050010005922.

97. Paul T Diamond Shawn D Gale Hea. Head injuries in skiers: an analysis of injury severity and outcome. *Brain Injury*. 2001;15(5):429-434. doi:10.1080/02699050116996.

98. Russell K, Meeuwisse WH, Nettel-Aguirre A, et al. Feature-specific terrain park-injury rates and risk factors in snowboarders: a case–control study. *British Journal of Sports Medicine*. 2013;48(1):23-28. doi:10.1136/bjsports-2012-091912.

99. Russell K, Meeuwisse W, Nettel-Aguirre A, et al. Comparing the characteristics of snowboarders injured in a terrain park who

present to the ski patrol, the emergency department or both. *International Journal of Injury Control and Safety Promotion*. 2014;21(3):244-251. doi:10.1080/17457300.2013.812665.

100. Brooks MA, Evans MD, Rivara FP. Evaluation of skiing and snowboarding injuries sustained in terrain parks versus traditional slopes. *Inj Prev*. 2010;16(2):119-122. doi:10.1136/ip.2009.022608.

101. Hunter RE. Skiing Injuries. *Am J Sports Med*. November 2016. doi:10.1177/03635465990270032101.

102. Harper MT, Chandnani VP, Spaeth J, Santangelo JR, Providence BC, Bagg MA. Gamekeeper thumb: Diagnosis of ulnar collateral ligament injury using magnetic resonance imaging, magnetic resonance arthrography and stress radiography. *Journal of Magnetic Resonance Imaging*. 1996;6(2):322-328. doi:10.1002/jmri.1880060211.

103. Miller RJ. Dislocations and fracture dislocations of the metacarpophalangeal joint of the thumb. *Hand Clin*. 1988;4(1):45-65.

104. Carr D, Johnson RJ, Pope MH. Upper extremity injuries in skiing. *Am J Sports Med*. 2016;9(6):378-383. doi:10.1177/036354658100900607.

105. Kocher MS, Dupré MM, Feagin JA. Shoulder Injuries from Alpine Skiing and Snowboarding. *Sports Medicine*. 1998;25(3):201-211. doi:10.2165/00007256-199825030-00006.

106. Deady LH, Salonen D. Skiing and Snowboarding Injuries: A Review with a Focus on Mechanism of Injury. *Radiologic Clinics of North America*. 2010;48(6):1113-1124.

107. Langran M. Increased Injury Risk Among First-Day Skiers, Snowboarders, and Skiboarders. *Am J Sports Med*. 2004;32(1):96-103. doi:10.1177/0095399703258684.

108. Harris JB. Spinal injuries in skiers and snowboarders. *Am J Sports Med*. 1999;27(4):546-546.

109. Kary JM. Acute Spine Injuries in Skiers and Snowboarders. *Current Sports Medicine Reports*. 2008;7(1):35-38. doi:10.1097/01.CSMR.0000308670.07441.4f.

110. Tarazi F, Dvorak MFS, Wing PC. Spinal Injuries in Skiers and Snowboarders. *Am J Sports Med*. 2016;27(2):177-180. doi:10.1177/03635465990270021101.

111. Ackery A, Hagel BE, Provvidenza C, Tator CH. An international review of head and spinal cord injuries in alpine skiing and snowboarding. *Injury Prevention*. 2007;13(6):368-375. doi:10.1136/ip.2007.017285.

112. Wakahara K, Matsumoto K, Sumi H, Sumi Y, Shimizu K. Traumatic Spinal Cord Injuries from Snowboarding. *Am J Sports Med*. 2017;34(10):1670-1674. doi:10.1177/0363546506288113.

113. Seino H, Kawaguchi S, Sekine M, Murakami T, Yamashita T. Traumatic Paraplegia in Snowboarders. *Spine*. 2001;26(11):1294.

114. Prall JA, Winston KR, Brennan R. Spine and Spinal Cord Injuries in Downhill Skiers. *Journal of Trauma and Acute Care Surgery*. 1995;39(6):1115.

115. Myles ST, Mohtadi NG, Schnittker J. Injuries to the nervous system and spine in downhill skiing. *Can J Surg*. 1992;35(6):643-648.

116. Bergstrøm KA, Askild O, Jørgensen NA, Ekeland A. Evaluation of skiing injuries by Injury Severity Score. *Scand J Med Sci Sports*. 1999;9(2):110-113.

117. Wasden CC, McIntosh SE, Keith DS, McCowan C. An Analysis of Skiing and Snowboarding Injuries on Utah Slopes. *Journal of Trauma and Acute Care Surgery*. 2009;67(5):1022-1026.

118. Deibert MC, Aronsson DD, Johnson RJ, Ettlinger CF, Shealy JE. Skiing Injuries in Children, Adolescents, and Adults*. *J Bone Joint Surg Am*. 1998;80(1):25.

119. Goulet C, Régnier G, Grimard G, Valois P, Villeneuve P. Risk factors associated with alpine skiing injuries in children. A case-control study. *Am J Sports Med*. 1999;27(5):644-650.

120. Hagel BE, Goulet C, Platt RW, Pless IB. Injuries Among Skiers and Snowboarders in Quebec. *Epidemiology*. 2004;15(3):279-286. doi:10.1097/01.ede.0000120044.62029.b4.

121. Sulheim S, Holme I, Rodven A, Ekeland A, Bahr R. Risk factors for injuries in alpine skiing, telemark skiing and snowboarding - case-control study. *British Journal of Sports Medicine*. 2011;45(16):1303-1309. doi:10.1136/bjsports-2011-090407.

122. Greenwald RM, Nesshoever M, Boynton MD. Ski Injury Epidemiology: A Short-Term Epidemiology Study of Injuries with Skiboards. In: *Skiing Trauma and Safety: Thirteenth Volume*. 100 Barr Harbor

Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 2000:119–119–8. doi:10.1520/STP12869S.

123. Macnab AJ, Smith T, Gagnon FA, Macnab M. Effect of helmet wear on the incidence of head/face and cervical spine injuries in young skiers and snowboarders. *Injury Prevention*. 2002;8(4):324-327. doi:10.1136/ip.8.4.324.

124. Lystad H. A Five-Year Survey of Skiing Injuries in Hemsedal, Norway. In: *Skiing Trauma and Safety: Seventh International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1989:32–32–9. doi:10.1520/STP19451S.

125. Moore SJ, Knerl D. Let it snow: how snowfall and injury mechanism affect ski and snowboard injuries in Vail, Colorado, 2011-2012. *J Trauma Acute Care Surg*. 2013;75(2):334-338. doi:10.1097/TA.0b013e31829467c9.

126. Carús L, Escorihuela M. Feature-specific ski injuries in snow parks. *Accident Analysis & Prevention*. 2016;95(Pt A):86-90. doi:10.1016/j.aap.2016.06.023.

127. Russell K, Meeuwisse W, Nettel-Aguirre A, et al. Characteristics of Injuries Sustained by Snowboarders in a Terrain Park. *Clin J Sport Med*. 2013;23(3):172-177. doi:10.1097/JSM.0b013e31827bd918.

128. Paletta GA, Warren RF. Knee injuries and Alpine skiing. Treatment and rehabilitation. *Sports Medicine*. 1994;17(6):411-423.

129. Johnson RJ. *Skiing Trauma and Safety*. ASTM International; 2006.

130. Furrer M, Erhart S, Frutiger A, Bereiter H, Leutenegger A, Ruedi T. Severe Skiing Injuries: A Retrospective Analysis of 361 Patients Including Mechanism of Trauma, Severity of Injury, and Mortality. *Journal of Trauma and Acute Care Surgery*. 1995;39(4):737.

131. Severe skiing injuries: A retrospective analysis of 361 patients including mechanism of trauma, severity of injury, and mortality. *Journal of Safety Research*. 1996;27(4):273. doi:10.1016/S0022-4375(97)81198-X.

132. Xiang H. Downhill skiing injury fatalities among children. *Injury Prevention*. 2004;10(2):99-102. doi:10.1136/ip.2003.004655.

133. Shealy J. Death in Downhill Skiing. In: *Skiing Trauma and Safety: Fifth International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1985:349–

349–9. doi:10.1520/STP46650S.

134. Weber CD, Horst K, Lefering R, et al. Major trauma in winter sports: an international trauma database analysis. *Eur J Trauma Emerg Surg*. 2016;42(6):741-747. doi:10.1007/s00068-015-0596-7.

135. Erhart S, Furrer M, Frutiger A, et al. [Blessings of technology? The severely injured skier--a result of technical equipment on the ski slope]. *Z Unfallchir Versicherungsmed*. 1994;87(1):22-26.

136. Chow TK, Corbett SW, Farstad DJ. Spectrum of injuries from snowboarding. *J Trauma*. 1996;41(2):321-325.

137. Matsumoto K, Miyamoto K, Sumi H, Sumi Y, Shimizu K. Upper extremity injuries in snowboarding and skiing: a comparative study. *Clin J Sport Med*. 2002;12(6):354-359.

138. Hagel BE, Pless IB, Goulet C, Platt RW, Robitaille Y. Effectiveness of helmets in skiers and snowboarders: case-control and case crossover study. *BMJ*. 2005;330(7486):281–0. doi:10.1136/bmj.38314.480035.7C.

139. Hagel BE, Pless B, Platt RW. Trends in emergency department reported head and neck injuries among skiers and snowboarders. *Can J Public Health*. 2003;94(6):458-462.

140. Kirkpatrick DP, Hunter RE, Janes PC, Mastrangelo J, Nicholas RA. The Snowboarder's Foot and Ankle. *Am J Sports Med*. November 2016. doi:10.1177/03635465980260021901.

141. Bürkner A, Simmen HP. [Fractures of the lower extremity in skiing - the influence of ski boots and injury pattern]. *Sportverletz Sportschaden*. 2008;22(4):207-212. doi:10.1055/s-2008-1027947.

142. Johnson RJ, Pope MH. Epidemiology and prevention of skiing injuries. *Ann Chir Gynaecol*. 1991;80(2):110-115.

143. Ruedl G, Linortner I, Schranz A, et al. Distribution of injury mechanisms and related factors in ACL-injured female carving skiers. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2009;17(11):1393-1398. doi:10.1007/s00167-009-0860-7.

144. Burtscher M, Gatterer H, Flatz M, et al. Effects of Modern Ski Equipment on the Overall Injury Rate and the Pattern of Injury Location in Alpine Skiing. *Clin J Sport Med*. 2008;18(4):355-357. doi:10.1097/MJT.0b013e31815fd0fe.

145. Demirağ B, Oncan T, Durak K. [An evaluation of knee ligament injuries encountered in skiers at the Uludag Ski Center]. *Acta Orthop Traumatol Turc*. 2004;38(5):313-316.

146. Johnson RJ, Ettlinger CF, Shealy JF. *Injury Trends and Risk Factors Involving ACL Injuries in Alpine Skiing*. Keynote Lecture during the 16th International …; 2005.

147. Stevenson H, Webster J, Johnson R, Beynnon B. Gender differences in knee injury epidemiology among competitive alpine ski racers. *Iowa Orthop J*. 1998;18:64-66.

148. Burtscher M, Sommersacher R, Ruedl G, Nachbauer W. Potential Risk Factors for Knee Injuries in Alpine Skiers. *Journal of ASTM International*. 2008;6(1):1-4. doi:10.1520/JAI101378.

149. Sulheim S. Helmet Use and Risk of Head Injuries in Alpine Skiers and Snowboarders. *JAMA*. 2006;295(8):919-924. doi:10.1001/jama.295.8.919.

150. Federiuk CS, Schlueter JL, Adams AL. Skiing, Snowboarding, and Sledding Injuries in a Northwestern State☆. *Wilderness & Environmental Medicine*. 2002;13(4):245-249. doi:10.1580/1080-6032(2002)013[0245:SSASII]2.0.CO;2.

151. Milan M, Jhajj S, Stewart C, Pyle L, Moulton S. Helmet use and injury severity among pediatric skiers and snowboarders in Colorado. *Journal of Pediatric Surgery*. 2017;52(2):349-353. doi:10.1016/j.jpedsurg.2016.11.001.

152. Ruedl G, Brunner F, Woldrich T, et al. Factors Associated With the Ability to Estimate Actual Speeds in Recreational Alpine Skiers. *Wilderness & Environmental Medicine*. 2013;24(2):118-123.

153. Sulheim S, Ekeland A, Holme I, Bahr R. Helmet use and risk of head injuries in alpine skiers and snowboarders: changes after an interval of one decade. *British Journal of Sports Medicine*. August 2016:bjsports–2015–095798. doi:10.1136/bjsports-2015-095798.

154. Shealy JE. Comparison of Downhill Ski Injury Patterns—1978–81 vs. 1988–90. In: *Skiing Trauma and Safety: Ninth International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1993:23–23–10. doi:10.1520/STP25556S.

155. Mogan JV, Davis PH. Upper extremity injuries in skiing. *Clin Sports Med*. 1982;1(2):295-308.

156. Florenes TW, Bere T, Nordsletten L, Heir S, Bahr R. Injuries among male and female World Cup alpine skiers. *British Journal of Sports Medicine*. 2009;43(13):973-978. doi:10.1136/bjsm.2009.068759.

157. Florenes TW, Nordsletten L, Heir S, Bahr R. Recording injuries among World Cup skiers and snowboarders: a methodological study. *Scand J Med Sci Sports*. 2011;21(2):196-205. doi:10.1111/j.1600-0838.2009.01048.x.

158. Bere T, Flørenes TW, Nordsletten L, Bahr R. Sex differences in the risk of injury in World Cup alpine skiers: a 6-year cohort study. *British Journal of Sports Medicine*. 2014;48(1):36-40. doi:10.1136/bjsports-2013-092206.

159. Haaland B, Steenstrup SE, Bere T, Bahr R, Nordsletten L. Injury rate and injury patterns in FIS World Cup Alpine skiing (2006-2015): have the new ski regulations made an impact? *British Journal of Sports Medicine*. 2016;50(1):32-36. doi:10.1136/bjsports-2015-095467.

160. Westin M, Alricsson M, Werner S. Injury profile of competitive alpine skiers: a five-year cohort study. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2012;20(6):1175-1181. doi:10.1007/s00167-012-1921-x.

161. Ekeland A, Dimmen S, Lystad H, Aune AK. Completion rates and injuries in alpine races during the 1994 Olympic Winter Games. *Scandinavian Journal of Medicine & Science in Sports*. 1996;6(5):287-290. doi:10.1111/j.1600-0838.1996.tb00472.x.

162. Bergstrøm KA, Bergstrøm A, Ekeland A. Organisation of safety measures in an Alpine World Junior Championship. *British Journal of Sports Medicine*. 2001;35(5):321-324. doi:10.1136/bjsm.35.5.321.

163. Pujol N, Blanchi M. *The Incidence of Anterior Cruciate Ligament Injuries Among Competitive Alpine Skiers a 25-Year Investigation*. The American …; 2007.

164. PU B, P K, M O, et al. [Recreational and competitive alpine skiing. Typical injury patterns and possibilities for prevention]. *Unfallchirurg*. 2014;117(1):24-32. doi:10.1007/s00113-013-2464-4.

165. Ekeland A, Nordsletten L, Lystad H, Lereim I. Previous Skiing Injuries in Alpine Olympic Racers. In: *Skiing Trauma and Safety: Eleventh Volume*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1997:7–7–7. doi:10.1520/STP18283S.

166. Margreiter R, Raas E, Lugger LJ. The risk of injury in experienced Alpine skiers. *Orthop Clin North Am*. 1976;7(1):51-54.

167. Steenstrup SE, Bere T, Bahr R. Head injuries among FIS World Cup alpine and freestyle skiers and snowboarders: a 7-year cohort study. *British Journal of Sports Medicine*. 2014;48(1):41-45. doi:10.1136/bjsports-2013-093145.

168. van Mechelen W, Hlobil H, Kemper HCG. Incidence, Severity, Aetiology and Prevention of Sports Injuries. *Sports Medicine*. 1992;14(2):82-99. doi:10.2165/00007256-199214020-00002.

169. Hasler RM, Berov S, Benneker L, et al. Are there risk factors for snowboard injuries? A case-control multicentre study of 559 snowboarders. *British Journal of Sports Medicine*. 2010;44(11):816-821. doi:10.1136/bjsm.2010.071357.

170. Bouter LM, Knipschild PG, Volovics A. Ability and Physical Condition in Relation to Injury Risk in Downhill Skiing. In: *Skiing Trauma and Safety: Seventh International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1989:94–94–9. doi:10.1520/STP19458S.

171. Bouter LM, Knipschild PG. Behavioral Risk Factors for Ski Injury: Problem Analysis as a Basis for Effective Health Education. In: *Skiing Trauma and Safety: Eighth International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1991:257–257–8. doi:10.1520/STP17651S.

172. Garrick JG. The epidemiology of ski injuries. *Minn Med*. 1971;54(1):17-18.

173. Cherpitel CJ, Meyers AR, Perrine MW. Alcohol consumption, sensation seeking and ski injury: a case-control study. *Journal of Studies on Alcohol*. 2015;59(2):216-221. doi:10.15288/jsa.1998.59.216.

174. Johnson RJ, Ettlinger CF, Shealy JE. Myths concerning alpine skiing injuries. *Sports Health*. 2009;1(6):486-492. doi:10.1177/1941738109347964.

175. Spörri J, Kröll J, Amesberger G, Blake OM, Muller E. Perceived key injury risk factors in World Cup alpine ski racing--an explorative qualitative study with expert stakeholders. *British Journal of Sports Medicine*. 2012;46(15):1059-1064. doi:10.1136/bjsports-2012-091048.

176. Machold W, Kwasny O, Gäler P, et al. Risk of Injury through

Snowboarding. *Journal of Trauma and Acute Care Surgery*. 2000;48(6):1109.

177. Chow TK, Corbett SW, Farstad DJ. Spectrum of Injuries from Snowboarding. *Journal of Trauma and Acute Care Surgery*. 1996;41(2):321.

178. Machold W, Kwasny O, Eisenhardt P, et al. Reduction of Severe Wrist Injuries in Snowboarding by an Optimized Wrist Protection Device: A Prospective Randomized Trial. *Journal of Trauma and Acute Care Surgery*. 2002;52(3):517.

179. Hedlund J. Risky business: safety regulations, risk compensation, and individual behavior. *Injury Prevention*. 2000;6(2):82-89. doi:10.1136/ip.6.2.82.

180. Muller E, Spörri J, Kröll J, Hörterer H. Equipment designed to reduce risk of severe traumatic injuries in alpine ski racing: constructive collaboration between the International Ski Federation, industry and science. *British Journal of Sports Medicine*. 2016;50(1):1-2. doi:10.1136/bjsports-2015-095689.

181. Bere T, Bahr R. Injury prevention advances in alpine ski racing: harnessing collaboration with the International Ski Federation (FIS), long-term surveillance and digital technology to benefit athletes. *British Journal of Sports Medicine*. 2014;48(9):738-738. doi:10.1136/bjsports-2014-093528.

182. Hildebrandt C, Mildner E, Hobenreich C, Raschner C. Accident prevention in recreational alpine skiing: how good is the familiarity about the fis-regulations? *British Journal of Sports Medicine*. 2011;45(4):352-352. doi:10.1136/bjsm.2011.084038.119.

183. Sulheim S, Ekeland A, Bahr R. Helmets Reduce the Risk of Head Injuries in Alpine Skiing Disciplines and Snowboarding. *Medicine & Science in Sports & Exercise*. 2004;36(Supplement):S288. doi:10.1097/00005768-200405001-01381.

184. BascheraDominik, M H, TaugwalderDavid, ExadaktylosAristomenis, RaabeAndreas. Association between Head Injury and Helmet Use in Alpine Skiers: Cohort Study from a Swiss Level I Trauma Center. *Journal of Neurotrauma*. 2015;32(8):557-562. doi:10.1089/neu.2014.3604.

185. Russell K, Christie J, Hagel BE. The effect of helmets on the risk of head and neck injuries among skiers and snowboarders: a meta-analysis. *Canadian Medical Association Journal*. 2010;182(4):333-

340. doi:10.1503/cmaj.091080.

186. Hagel B, Pless IB, Goulet C, Platt R, Robitaille Y. The effect of helmet use on injury severity and crash circumstances in skiers and snowboarders. *Accident Analysis & Prevention*. 2005;37(1):103-108.

187. Matter P, Müller W, Ott C. Frequency of ski injuries in the Davos region. *Orthop Clin North Am*. 1976;7(1):31-35.

188. Lystad H. Collision Injuries in Alpine Skiing. In: *Skiing Trauma and Safety: Seventh International Symposium*. 100 Barr Harbor Drive, PO Box C700, West Conshohocken, PA 19428-2959: ASTM International; 1989:69–69–6. doi:10.1520/STP19455S.

189. Jørgensen U, Fredensborg T, Haraszuk JP, Crone K-L. Reduction of injuries in downhill skiing by use of an instructional ski-video: a prospective randomised intervention study. *Knee Surgery, Sports Traumatology, Arthroscopy*. 1998;6(3):194-200. doi:10.1007/s001670050098.

190. Kröll J, Spörri J, Gilgien M, Schwameder H, Muller E. Effect of ski geometry on aggressive ski behaviour and visual aesthetics: equipment designed to reduce risk of severe traumatic knee injuries in alpine giant slalom ski racing. *Br J Sports Med*. 2015;50(1):bjsports–2015–095433–25. doi:10.1136/bjsports-2015-095433.

191. FIS Medical Guide page 37 Edition 2013.

192. Postma WF, West RV. Anterior Cruciate Ligament Injury-Prevention Programs. *J Bone Joint Surg Am*. 2013;95(7):661-669. doi:10.2106/JBJS.L.00343.

193. Westin M, Reeds-Lundqvist S, Werner S. The correlation between anterior cruciate ligament injury in elite alpine skiers and their parents. *Knee Surg Sports Traumatol Arthrosc*. 2016;24(3):697-701. doi:10.1007/s00167-014-2974-9.

194. Bahr R. Understanding injury mechanisms: a key component of preventing injuries in sport. *British Journal of Sports Medicine*. 2005;39(6):324-329. doi:10.1136/bjsm.2005.018341.

195. Stenroos A, Savolainen M, Sandelin H. Long-Term Effects of Knee Injuries in Former Ski Racers. *Orthop Muscular Syst*. 2017;06(03). doi:10.4172/2161-0533.1000241.

196. Westin M, Werner S. ALPINE SKIING - INJURY PROFILE, ACL INJURY

RISK FACTORS, AND PREVENTION. *Published by Karolinska Institutet*. September 2017:1-78.

197. Dekker R, van der Sluis CK, Groothoff JW, Eisma WH, Duis ten HJ. Long-term outcome of sports injuries: results after inpatient treatment. *Clin Rehabil*. 2003;17(5):480-487. doi:10.1191/0269215503cr639oa.

198. Tall RL, DeVault W. Spinal injury in sport: epidemiologic considerations. *Clin Sports Med*. 1993;12(3):441-448.

199. Van Mechelen W, Hlobil H, Kemper HC. Incidence, severity, aetiology and prevention of sports injuries. A review of concepts. *Sports Medicine*. 1992;14(2):82-99.

200. Haida A, Coulmy N, Dor F, et al. Return to Sport Among French Alpine Skiers After an Anterior Cruciate Ligament Rupture: Results From 1980 to 2013. *Am J Sports Med*. 2016;44(2):324-330. doi:10.1177/0363546515612764.

201. Higgins RW, Steadman JR. Anterior cruciate ligament repairs in world class skiers. *Am J Sports Med*. 1987;15(5):439-447. doi:10.1177/036354658701500503.

202. Pressman A, Johnson DH. A review of ski injuries resulting in combined injury to the anterior cruciate ligament and medial collateral ligaments. *Arthroscopy*. 2003;19(2):194-202. doi:10.1053/jars.2003.50054.

203. Jordan M, Heard M, Doyle-Baker P, Aagaard P, Herzog W. Associated pathology and limb asymmetry in ACL reconstructed elite alpine racers. 2017.

204. Viola RW, Steadman JR, Mair SD, Briggs KK, Sterett WI. Anterior cruciate ligament injury incidence among male and female professional alpine skiers. *Am J Sports Med*. 1999;27(6):792-795. doi:10.1177/03635465990270061701.

205. Lohmander LS, Roos H. Knee ligament injury, surgery and osteoarthrosis: Truth or consequences? *Acta Orthopaedica Scandinavica*. 2009;65(6):605-609. doi:10.3109/17453679408994613.

206. Lohmander LS, Östenberg A, Englund M, Roos H. High prevalence of knee osteoarthritis, pain, and functional limitations in female soccer players twelve years after anterior cruciate ligament injury. *Arthritis & Rheumatology*. 2004;50(10):3145-3152.

doi:10.1002/art.20589.

207. Roos H, Laurén M, Adalberth T, Roos EM, Jonsson K, Lohmander LS. Knee osteoarthritis after meniscectomy: Prevalence of radiographic changes after twenty-one years, compared with matched controls. *Arthritis & Rheumatology*. 1998;41(4):687-693. doi:10.1002/1529-0131(199804)41:4<687::AID-ART16>3.0.CO;2-2.

208. Honkonen SE. Degenerative Arthritis After Tibial Plateau Fractures. *Journal of Orthopaedic Trauma*. 1995;9(4):273.

209. Mückley T, Kruis C, Schütz T, Brucker P, Bühren V. [Fractures of the lower leg in professional skiers]. *Sportverletz Sportschaden*. 2004;18(1):22-27. doi:10.1055/s-2004-812899.

210. Müller D, Sandmann GH, Martetschläger F, Stöckle U, Kraus TM. [Tibial plateau fractures in alpine skiing--return to the slopes or career end?]. *Sportverletz Sportschaden*. 2014;28(1):24-30. doi:10.1055/s-0034-1366146.

211. Kraus TM, Martetschläger F, Müller D, et al. Return to sports activity after tibial plateau fractures: 89 cases with minimum 24-month follow-up. *Am J Sports Med*. 2012;40(12):2845-2852. doi:10.1177/0363546512462564.

212. Brown AW, Elovic EP, Kothari S, Flanagan SR, Kwasnica C. Congenital and Acquired Brain Injury. 1. Epidemiology, Pathophysiology, Prognostication, Innovative Treatments, and Prevention. *Archives of Physical Medicine and Rehabilitation*. 2008;89(3):S3-S8.

213. Guskiewicz KM, Broglio SP. Acute sports-related traumatic brain injury and repetitive concussion. In: *Handbook of Clinical Neurology*. Vol 127. Handbook of Clinical Neurology. Elsevier; 2015:157-172. doi:10.1016/B978-0-444-52892-6.00010-6.

214. McCrory P, Meeuwisse W, Dvorak J, et al. Consensus statement on concussion in sport-the 5(th) international conference on concussion in sport held in Berlin, October 2016. *British Journal of Sports Medicine*. 2017;51(11):bjsports–2017–097699–847. doi:10.1136/bjsports-2017-097699.

215. Ski Sport Finland jäsenrekisteri 2008.

216. Müller ME, Nazarian S, Koch P. Principes de la Classification AO des Fractures. In: *Classification AO Des Fractures*. Berlin, Heidelberg: Springer Berlin Heidelberg; 1987:4-7. doi:10.1007/978-3-662-06263-0_2.

217. Jennett B. ASSESSMENT OF OUTCOME AFTER SEVERE BRAIN DAMAGE A Practical Scale. *The Lancet*. 1975;305(7905):480-484. doi:10.1016/S0140-6736(75)92830-5.

218. O'Neill DF. Wrist injuries in guarded versus unguarded first time snowboarders. *Clinical Orthopaedics and Related Research*. 2003;409(409):91-95. doi:10.1097/01.blo.0000057785.10364.dc.

219. Rønning R, Rønning I, Gerner T, Engebretsen L. The Efficacy of Wrist Protectors in Preventing Snowboarding Injuries. *Am J Sports Med*. November 2016. doi:10.1177/03635465010290051001.

220. Stenroos A, Handolin L. Incidence of Recreational Alpine Skiing and Snowboarding Injuries: Six Years Experience in the Largest Ski Resort in Finland. *Scand J Surg*. 2015;104(2):127-131. doi:10.1177/1457496914532249.

221. Duncan JB, Hunter R, Purnell M, Freeman J. Meniscal Injuries Associated With Acute Anterior Cruciate Ligament Tears in Alpine Skiers. *Am J Sports Med*. 2016;23(2):170-172. doi:10.1177/036354659502300208.

222. George A Paletta JR, Levine DS, O'Brien SJ, Wickiewicz TL, Warren RF. Patterns of meniscal injury associated with acute anterior cruciate ligament injury in skiers. *Am J Sports Med*. 2016;20(5):542-547. doi:10.1177/036354659202000510.

223. Blitzer CM, Johnson RJ, Ettlinger CF, Aggeborn K. Downhill skiing injuries in children. *Am J Sports Med*. 2016;12(2):142-147. doi:10.1177/036354658401200210.

224. Schulak DJ, Gunn DR. Fractures of the Tibial Plateaus: A Review of the Literature. *Clinical Orthopaedics and Related Research*. 1975;109:166.

225. Ungerholm S, Engkvist O, Gierup J, Lindsjö U, Balkfors B. Skiing Injuries in Children and Adults: A Comparative Study from an 8-Year Period. *International Journal of Sports Medicine*. 2008;04(04):236-240. doi:10.1055/s-2008-1026041.

226. MORROW PL, McQUILLEN EN, Eaton LA, Bernstein CJ. Downhill ski fatalities: the Vermont experience. *J Trauma*. 1988;28(1):95-100.

227. Haider AH, Saleem T, Bilaniuk JW, Barraco RD. An Evidence Based Review: Efficacy of Safety Helmets in Reduction of Head Injuries in Recreational Skiers and Snowboarders. *J Trauma Acute Care Surg*. 2012;73(5):1340-1347. doi:10.1097/TA.0b013e318270bbca.

228. Materials ASFT. *Annual Book of ASTM Standards 2013*. 2013.

229. Shealy JE, Ettlinger CF, Johnson RJ. How Fast Do Winter Sports Participants Travel on Alpine Slopes? *Journal of ASTM International*. 2005;2(7):1-8. doi:10.1520/JAI12092.

230. Williams R, Delaney T, Nelson E, Gratton J, Laurent J, Heath B. Speeds Associated With Skiing and Snowboarding. *http://dxdoiorg/101580/06-WEME-OR-037R11*. 2009;18(2):102-105. doi:10.1580/06-WEME-OR-037R1.1.

231. Steenstrup SE, Mok K-M, McIntosh AS, Bahr R, Krosshaug T. Head impact velocities in FIS World Cup snowboarders and freestyle skiers: Do real-life impacts exceed helmet testing standards? *British Journal of Sports Medicine*. July 2017:bjsports–2016–097086. doi:10.1136/bjsports-2016-097086.

10. APPENDIX

Written questionnaire send to injured skiers.

		MÄÄRITELMÄ	DATAN KUVAUS
1	Sukunimi	henkilön sukunimi	
2	Etunimi	henkilön etunimi	
3	Henkilötunnus	henkilötunnus	
4	Puhelinnumero	suostumuksen antajan puhelinnumero	
5	Suostumus	keneltä suostumus saatu (suhde)	suostumuksen antajan nimi ja suhde rekisteröitävään (esim. isä)
6	Suostumus pvm	milloin suostumus on saatu	
7	Päivämäärä	onnettomuuden päivämäärä	
8	Seura	seuran virallinen lyhenne	
9	Case ID	tapauksen tunnistekoodi	
10	Sukupuoli	syntymäsukupuoli	1 = mies, 2 = nainen
11	Ikä	ikä onnettomuushetkellä	
12	Sarja	sarjan virallinen lyhenne onnettomuushetkellä	1 = M9, 2 = N9, 3 = M11, 4 = N11, 5 = M13, 6 = M15, 7 = N15, 8 = M17, 9 = N17, 10 = MYL, 11 = NYL
13	Onnettomuuspaikka	tapahtuiko onnettomuus Suomessa vai ulkomailla	1 = Suomessa, 2 = Ulkomailla, 999 = ei tietoa
14	Onnettomuustilanne	missä tilanteessa onnettomuus tapahtui	1 = harjoitus, 2 = kilpailu, 3 = muu, 999 = ei tietoa
15	Laji	laji onnettomuuden tapahtuessa	1 = P, 2 = SP, 3 = SG, 4 = DH, 5 =muu, 999 = ei tietoa
16	Vapaa/rata	tapahtuiko onnettomuus vapaa- vai ratalaskussa	1 = vapaalasku, 2 = ratalasku, 999 = ei tietoa
17	Lumen laatu	oliko kyseessä luonnon- vai keinolumi	1 = luonnonlumi, 2 = keinolumi, 999 = ei tietoa
18	Rinteen pinta	kuvaus rinteen pinnasta	1= palkitettu / jäätikköjää, 2 = kova / kompakti, 3 = pehmeä, 4 = sohjoinen, 5 = suolattu, 999 = ei tietoa
19	Ratavalli	jos onnettomuus tapahtui radalla, oliko radalla merkittävät reunavallit	1 = kyllä, 99 = ei, 999 = ei tietoa
20	Verkko	oliko onnettomuuskohta verkotettu	1 = oli verkotettu, laskija meni verkkoihin, 2 = oli verkotettu, laskija ei mennyt verkkoihin, 99 = ei ollut verkotettu
21	Sää	säätilan kuvaus	1 = kirkas, 2 = pilvinen, 3 = vesisade, 4 = lumisade, 5 = sumu, 999 = ei tietoa
22	Valaistus	valaistuksen kuvaus	1 = luonnonvalo, 2 = keinovalo, 999 = ei tietoa
23	Tuuli	tuulen voimakkuuden kuvaus	1 = tyyni, 2 = tuulinen, 3 = kova tuuli, 999 = ei tietoa
24	Lämpötila	lämpötila onnettomuushetkellä	1 = alle -20, 2 = -10 - -20, 3 = 0 - -10, 4 = +1 - +10, 5 = yli + 10, 999 = ei tietoa
25	Kypärä	oliko laskijalla onnettomuushetkellä kypärä päässä	1 = kyllä, 99 = ei, 999 = ei tietoa
26	Selkäpanssari	oliko laskijalla onnettomuushetkellä selkäpanssari	1 = kyllä, 99 = ei, 999 = ei tietoa
27	Vammamekanismi	millä mekanismilla vamma syntyi	1 = törmäys laskualueella, 2 =törmäys laskualueen ulkopuolella (ajautuminen sivuun), 3 = putoaminen laskualueen ulkopuolella (ajautuminen sivuun), 4 = kaatuminen samalla tasolla, 5 = kaatuminen hyppyrissä, 6 = vääntyminen ilman kaatumista, 7 = paleltuminen, 8 = rasitusvamma, 9 = muu, 999 = ei tietoa
28	Vammamekanismin tarkennus	vapaa kuvaus vammamekanismista	vapaa tekstikenttä (esim. törmäys toiseen laskijaan, törmäys puuhun, törmäys verkkoon sekä verkon kuvaus jne.)

29	Vammautunut ruumiinosa	loukkaantuneen ruumiinosan määritelmä	1 = pää/kasvot, 2 = kaula/kaularanka, 3 = solisluu, 4 = olkanivel, 5 = olkavarsi, 6 = kyynärnivel, 7 = kyynärvarsi, 8 = ranne, 9 = käsi ja sormet, 10 = thorax, 11 = rintaranka, 12 = vatsa, 13 = lanneranka, 14 = lantio, 15 = lonkkanivel, 16 = reisi, 17 = polvinivel, 18 = sääri, 19 = nilkkanivel, 20 = jalkaterä/varpaat, 999 = ei tietoa
30	Puoli	vammautuneen ruumiinosan puoli	1 = oikea, 2 = vasen, 3 = sentraalinen, 999 = ei tietoa
31	Vammatyyppi	vammatyypin määritelmä	1 = ruhje, 2 = haava, 3 = venähdys, 4 = sijoiltaan meno, 5 = nivelsidevamma, 6 = murtuma, 7 = rasitusmurtuma, 8 = repeämä, 9 = rasitusvamma, 10 = aivotärähdys, 11 = paleltuminen, 12 = muu, 999 = ei tietoa
32	Vammadiagnoosi	vammadiagnoosin nimi	vapaa tekstikenttä, vammadiagnoosin kuvaus mahdollisimman tarkasti
33	Kuolema	aiheuttiko vamma kuoleman	1 = kyllä, 99 = ei, 999 = ei tietoa
34	AIS	vamman AIS-koodi	Abbreviated Injury Scale – koodi (AIS 2005)
35	Sairaalahoito	vaatiko vamman hoito sairaalahoitoa	1 = kyllä, 99 = ei, 999 = ei tietoa
36	LOS	sairaalahoidon pituus	LOS (Length of stay) vuorokausina, juokseva numero, 999 = ei tietoa
37	Operatiivinen hoito	vaatiko vamman hoito toimenpiteitä	1 = kipsaus, 2 = leikkaus, 3 = muu, 99 = muu, 999 = ei tietoa
38	Operaation nimi	operatiivisen hoidon kuvaus	Operaation Nomesko-koodi ja nimi kirjoitettuna, 999 = ei tietoa
39	Sairauspoissaolo	harjoittelupoissaolon pituus	kokonaisluku vuorokausina, 9999 = uran loppuminen, 999 = ei tietoa
40	Subjektiivinen haitta	subjektiivinen tuntemus EDL-haitasta 6 kk vammasta	EDL (Every Day Living) – haitta, 1 = ei haittaa, 2 = lievä haitta, 3 = kohtalainen haitta, 4 = suuri haitta, 999= ei tietoa
41	Alppihaitta	haittaako vamma alppihiihtoa 6 kk vammasta	1 = ei haittaa, 2 = lievä haitta, 3 = kohtalainen haitta, 4 = suuri haitta, 5 = estää alppihiihdon, 999= ei tietoa

Levi First Aid Injury Form

Levi Ensiapu	
Päivämäärä	Potilasnumero
Ikä	
Sukupuoli	1=Nainen 2=Mies
Paikka	
Välineet	1=Sukset, 2= Lumilauta, 3= Telemark, 4= muu
Mekanismi	1=Kaatuminen 2=Vääntyminen 3=Törmääminen henkilöön 4=Hyppyri 5= Törmääminen kiinteään esineeseen 6=Ei tiedossa
Loukkaantunut ruumiin osa	1=Pää 2=Niska 3= Selkä 4=Rintakehä ja vatsa 5=Olkapää 6= Kyynärpää ja käsivarsi 7=Ranne 8= Käsi 9=Peukalo 10= Lonkka ja reisi, 11=Polvi 12=Sääri 13=Nilkka ja jalka 14=Muu
Evakuaatio	1=Hakeutui itse 2=Skipatrol haki 3= ei tiedossa
Vammanlaatu	1=Ruhje 2=Venähdys 3=Murtuma susp 4=Avomurtuma 5=Haava 6=Aivotärähdys 7=Tajuttomuus yli 10 min 8=Dislokaatio 9=muu
Hoito	1=KKK 2=Haavasidos 3=Repositio 4= Lastotus 5=Mitella
Triage	1=Hoidettu paikan päällä 2=Ohjattu jatkotutkimuksiin 3= Ambulanssi 4=Helikopteri 5=Ei tietoa
Virheasento	1=Kyllä 2=Ei
Muuta	

11. ORIGINAL PUBLICATIONS